Resolving Conflicts and Uncertainty in Water Management

Proceedings of the 45th Annual Conference
of the
Canadian Water Resources Association
Kingston, Ontario

Edited by Dan Shrubsole

Published with the assistance of
Environment Canada
Ontario Ministry of the Environment

Canadian Water Resource Association
Association Canadienne des Ressources Hydriques
1992

Resolving Conflicts and Uncertainty in Water Management

-01701/

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ISBN 9694535-1-5

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Canadian Water Resources Association
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P.O. Box 1329
Cambridge, Ontario
Canada, N1R 7G6

Canadian Cataloguing in Publication Data

Canadian Water Resources Association. Conference
(45th : 1992 : Kingston, Ont.)
Resolving conflicts and uncertainty in water
management

Includes bibliographical references.
ISBN 0-9694535-1-5

1. Watershed management - Canada - Congresses.
2. Water resources development - Canada - Congresses.
3. Conflict management - Congresses. I. Shrubsole,
Dan, 1958- . II. Title.

TC426.C363 1992 333.91'00971 C92-094266-0

Printed on recycled paper

PREFACE

I would like to thank all the authors for their cooperation in agreeing to submit a paper and participate in the conference. They are all people who have busy schedules and their willingness to share their views with others is greatly appreciated. It is hoped that the insights they provide here will be of interest and assistance to readers.

Several people were particularly helpful in the preparation of this volume. I would like to thank the anonymous reviewers who reviewed some of the papers. Pamela Brown, Patricia Chalk, and Eugenia Sagardia played crucial roles in preparing the manuscript for production. The Canadian Water Resources Association and conference organizing committee comprised of Jim Bauer, Paul Frigon, Patricia M. Howorth, Stephen Knechtel, Ivan Lorant and Ed Watt have been very supportive. In addition, Anthony Dorcey of the University of British Columbia, Frank Quinn of Environment Canada, and Ken Thomson of Golder Associates played vital roles in the organization of the plenary program.

Financial support for the preparation of the figures and text was provided by Environment Canada and the Ontario Ministry of the Environment.

The papers included in these proceedings were selected on the basis of extended abstracts. The papers are published with minor revisions for editorial purposes. It is believed that these changes have changed neither the substance nor intentions of the authors. Accordingly, the views expressed herein are those of the authors, and do not necessarily reflect the views of the Canadian Water Resources Association.

While all the above mentioned individuals provided assistance in the preparation of this volume of papers, any editorial shortcomings or errors are the responsibility of the editor.

Dan Shrubsole
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April 1992

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RESOLVING CONFLICTS AND UNCERTAINTY IN WATER MANAGEMENT

In 1981, a national symposium entitled "River Basin Management: Canadian Experiences" was co-organized by the Canadian Water Resources Association (CWRA). It was designed "to focus attention upon strategic issues associated with river basin management in Canada" (Mitchell and Gardner, 1983, 1). "Innovation in River Basin Management" was the theme of the CWRA's 43rd Annual Conference. At that time, it was agreed that all water managers had to respond in an efficient, effective and innovative manner in order to address the challenges which confronted them (McNeil and Windsor, 1990). At both of these gatherings, the presence of conflict and uncertainty was identified as significant obstacles. Hence, the focus of this volume of papers considers if and how conflicts and uncertainty can be resolved.

The papers are classified according to the how conflicts and uncertainty might be resolved, and on the basis of the submitted papers. This book is divided into three sections: (1) watershed planning and impact assessment, (2) monitoring, analysis and modelling, and (3) economic instruments.

In the first chapter, Dorcey provides a context for the consideration of the individual papers. Dorcey, on behalf of the CWRA Technical Bureau, issues a challenge for all water managers to practice the principles of sustainable development. His discussion highlights the pervasive conflict and uncertainty in managing water, and suggests that decision making will be more difficult in the future unless changes are made. He maintains that the implementation of sustainable development principles can meet future demands. However, if this goal is to be achieved, the public, professional managers and politicians must adopt new values, new science, new policies and new institutional arrangements. This is the torch which the individual authors have been asked to carry.

In the first section of the book, ten authors consider watershed planning and impact assessment. Walker examines opportunities for the expanded use of negotiation which would improve institutional arrangements for groundwater management. In their assessment of policies and institutional arrangements for integrated catchment management in Western Australia, Mitchell and Hollick note that one difficulty concerned the lack of attention in defining the products (*e.g.*, guidelines, plans) to be achieved.

The effective implementation of sustainable water management in Canada will require the establishment of tangible objectives.

The next five chapters examine aspects of water management and impact assessment in Canada. Breton, Maunder and Snodgrass examine the application of science and policy in watershed planning. The management of value, cognitive, and interest conflicts in the context of the Great Lakes are described by Cuthbert. Yu and Chubbuck, and Evans and McCormick note the issues associated with revitalizing two hydroelectric generating facilities. In an urban context, Ontario Hydro is confronted with the challenges of minimizing impact on the environment, and preserving historical features. In a northern context, minimizing environmental impacts and meeting the needs of the Aboriginal People are significant issues confronting the Corporation. The use of the Federal Environmental Assessment Review Process is considered by Stolte and Sadar.

The final three chapters of this first section consider water and land-related management. Fitzgibbon notes that the present trend in providing for natural channel design is, in part, the result of the public's changing values. This conclusion is supported by Carlisle and Smith who also describe some of the obstacles in effectively managing wetlands in Ontario. Watson reviews the institutional arrangements for the management of nitrate pollution in the United Kingdom. The understanding of the nitrate problem is fraught with uncertainty, and institutional arrangements to address the problem are fragmented and ineffective.

The second section highlights the roles of monitoring, analysis and modelling in resolving conflicts and uncertainty. Collectively, these authors address many issues related to the role of science in sustainable development and water management. MacRae and Rowney highlight how a better understanding of moderate flow events can facilitate more effective stormwater management. The use of expert systems, remote sensing, and conflict analysis are described by Montas and Madramootoo, Muzik, and LeBlanc and El-Jabi respectively.

The next three chapters evaluate the use of statistical analysis in water management. Rae and McClennan appraise the ability of selected computer program packages to estimate future flows. This research has important applications in areas such as the generation of hydroelectricity. During the 1980s, floods inflicted millions of dollars in damages on Canadians. Paine and Watt note the topographic, hydrologic, and hydraulic uncertainty associated with the preparation of floodplain maps. They suggest that the use of maps should be compatible with the level of uncertainty. Muzik and Chang describe a physically-based stochastic model of the rainfall-runoff process which can be used to generate hydrographs. They maintain that this approach is more appropriate than waiting for 'more data' to reduce uncertainty.

The final section of this volume deals with economic instruments. The first three papers focus attention on the supply of water to households. Renzetti reviews the problem of setting an optimal price for water. The pricing of water is an important element of the *Federal Water Policy*, and it is likely to be at the heart of future management strategies. A different perspective on water supply management is provided by Welker, Houghton and Jany. They develop a predictive model of water demand which could be used to announce water bans in a more timely fashion. The savings associated with the installation of water conservation measures in government buildings are examined by Tate and MacMillan. Bjonback utilizes economic principles to survey how recreational users responded to drought conditions. Although economics is not the only value set to be applied in decision making, economic techniques such as contingent valuation and the travel cost method significantly influence the allocation of water resources.

The papers contained in this volume highlight the diversity and complexity of considerations involved in water management. While the papers indicate that conflict and uncertainty cannot be removed from water management activities, they do suggest that progress is being made. The role of the public and the use of economic principles continue to receive considerable attention from managers and researchers. A better appreciation of a wider-range of values is apparent in the management of wetlands. The 1990s have also realized a greater sensitivity to the need to integrate water and land-based resources. This trend is evident in the *Federal Water Policy*, and water policy discussion papers presently circulating in Alberta and Nova Scotia. 'Water management science' has responded to the suggestion to combine our understanding of human and natural systems. Geographic information systems, remotely-sensed data, and other computer-based approaches are often used in conjunction with role playing simulations.

While there have been some areas of progress, some issues must be addressed more adequately.

First, it is important that we develop, in Mitchell's and Hollick's terms, a philosophy, process, and product which contribute to the understanding about the objectives for sustainable water management. At present, the philosophy is apart from, rather than a part of, process (*e.g.*, impact assessment, watershed planning) and product (*e.g.*, referrals, grants and subsidies, regulations). These three elements of our governance system must be better aligned to achieve sustainable development. In this regard, institutional arrangements must be responsive to the public's needs, and allow for the formulation and implementation of balanced policies.

Second, there is a need for water managers to clarify the nature of planning processes. While no single perfect administrative system exists, it appears that water planning is often perceived as taking many disjointed forms. For instance, how are processes like municipal planning, impact assessment, and watershed planning linked? If these exercises are not conducted in a clear and appropriate manner, a perpetual 'do loop' could be the result. Shared databases can assist in resolving conflicts and reducing uncertainties arising from these different planning initiatives.

Third, we must develop effective mechanisms to resolve conflicts, and be more comfortable with making decisions in the presence of uncertainty. These considerations imply that change is going to be a constant element in the management of water resources. The new values, new science, new politics, and new institutional arrangements, which are associated with implementation of sustainable development and the resolution of conflict and uncertainty, require all participants in the water management process to be more adaptive.

I can better appreciate the significant difficulties associated with meeting Dorcey's challenge: the implementation of sustainable development in water management. Water management is a process of making balanced decisions among conflicting objectives and requires that trade-offs be made. Formulating and implementing that process and its associated products will be the focus of many other books and conferences in the future.

Dan Shrubsole
Editor

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Mitchell, B. and J.S. Gardner. (1983). *River Basin Management: Canadian Experiences*. Waterloo: University of Waterloo, Department of Geography Publication Series No. 20.

CHAPTER 1

SUSTAINABLE DEVELOPMENT PRINCIPLES FOR WATER RESOURCES MANAGEMENT IN CANADA: TOWARDS A NEW CONSENSUS[1]

A.H.J. Dorcey

INTRODUCTION

The evolving ethic of sustainable development not only reinforces but also extends long recognized principles of water resources management. However, it has proven to be exceedingly difficult to put these principles into practice in the past and the outlook is that it is going to become even more challenging in the future. In this situation, it is critically important to develop a consensus on a revised set of principles that can be put into practice in the sustainable development of Canadian water resources. The CWRA could play a lead role by producing a set of principles that its members would then implement. The time is right as most provinces are in the process of developing new water policy statements to complement the *Federal Water Policy* (Environment Canada, 1987).

Despite the principles articulated in textbooks and government policy documents, it is by no means clear to me that there is a broadly-based consensus in practice, either within or outside of the water community, about the principles that should guide water resources management in Canada. I believe that this is a fundamental reason why principles have existed but not been put into practice. The failure of professional, political and public commitment in putting principles into practice is rooted in the lack of a real consensus. Now that we are beginning to see fresh reasons to apply old principles and revise them to reflect an ethic of sustainable development, it is most appropriate and timely to initiate debate.

The purpose of this statement is to stimulate debate within CWRA by suggesting questions that need to be addressed. It is adapted from a longer paper that has been submitted for publication in the *Canadian Water Resources Journal.*

PRINCIPLES AND PRACTICES

Textbooks on water management have for more than a decade recognized at least partially some of the key constituents of principles that are central to sustainable development, but it is taking time for these to be translated into formal policies in Canada and practice still lags much further behind. The principles of water management specifically appropriate to the evolving ethics of sustainable development are only beginning to be elaborated in the literature and translated into new policies; the major problems of putting them into practice are still ahead.

Already by the mid 1970s, experiments with modern principles of water management were well advanced in Canada (Dorcey, 1987). They had been catalysed in the 1960s by growing concerns with pollution and other undesired consequences of economic development. River basin planning and impact assessment processes were coming to be seen as essential parts of management. Out of the earlier concepts of multiple purpose river basin development using multiple means to pursue multiple objectives, came ideas of integrated resources management. The need to consider not only economic but also environmental and social consequences of water resources development was recognized in new valuation methods and procedures. Opportunities for involving the public in impact assessment and planning were considered to be essential to the process of evaluation and a fundamental element of regional approaches to management. Such principles are well reflected in the *Federal Water Policy* that was eventually published in 1987 after much discussion.

Over the last two decades, however, it has proven to be extremely difficult to put such principles into practice. There are two interrelated sets of reasons. Firstly, the ambitious management experiments launched in the early 1970s were fraught with difficulties. They called for knowledge about natural and human systems that often did not exist. They also demanded unprecedented abilities to conduct interdisciplinary analyses, and interpersonal and interorganizational relations. The result was profound disappointment among all parties with frustrations, delays and failure to deliver promised improvements. Secondly, there was not the political will and associated budgetary commitments to persevere. In the late 1970s and early 1980s, disappointments with the results of the management experiments combined with increasingly serious problems with the Canadian economy led to emphasis on expenditure reduction, and a reversion to more partial and traditional resource management procedures together with a search for more strategic approaches.

In the late 1980s and early 1990s, the evolving ethic of sustainable development has renewed interest in refining and advancing the earlier principles of water management. The Round Tables on the Environment and the Economy that have been established by federal, provincial and territorial governments are exploring sustainable development principles and formulating recommendations for putting them into practice. In varying ways, they are building on the Brundtland definition - " sustainable development is development which meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). Despite the differences in interpretation of this definition, there is a growing consensus that sustainable development involves much more attention to the environment, social and economic consequences than in the past and that critical differences of opinion relate to the rates and distribution of adaptation: How quickly should development adapt so as to be more sustainable? Who should incur the costs and reap the benefits of more sustainable development?

OLD AND NEW CHALLENGES

Sustainable development is providing a new context within which to consider the principles and practice of water resources management. Since a large part of what will be required by sustainable development strategies involves the implementation of well established principles variously referred to as 'comprehensive river basin development', 'integrated resources management' and 'strategic watershed planning', it is essential to examine how principles have been applied in Canada and to assess their reasons for success and failure in practice. Unless the difficulties that have been encountered in the past in implementing recognized principles can be overcome, it is unlikely that new principles reflecting a sustainable development ethic will be successfully implemented because they pose most of the same difficulties but in much more challenging guises.

There are a number of ways in which water management in the sustainable development of river basins will become more challenging:

Increased number of systems

Water resources management in a river basin becomes progressively more complex with the growing recognition of the variety of natural (bio-physical) and human (socio-economic and political-institutional) systems and subsystems to be considered. The more developed the basin and its associated systems and the more detailed the analysis, the greater the complexity to be dealt with.

Expanded spatial boundaries

Along with the recognition of the diversity of systems comes the necessity to consider much wider spatial bounds. Watersheds not only have to be examined as subsystems of river basins but the wider boundaries of associated bio-physical, socio-economic and political-institutional systems that create important interdependencies with other river basins at the regional, continental and global level have to be taken into account (*e.g.*, climate change and export markets for basin resource products).

Lengthened time scales

Concern for the preservation of options for future generations draws attention to much longer time periods. This implies examining not only the longer term consequences of proposed developments but also the possibilities for reversing the consequences of past commitments.

Greater demands on science

The knowledge needed to make informed decisions in water management places immense demands on science. The questions raised by the sustainable development perspective on river basin management reveal major gaps in knowledge about the behaviour of diverse natural and human systems.

Pervasive uncertainty

Recognition that many of these gaps in knowledge cannot be eliminated in the nearer future and that uncertainty is to a substantial extent inherent, makes it evident that management will involve extensive judgements about both facts and values that will frequently be intimately entwined.

Heightened ethical concerns

There is a growing appreciation of the ethical and moral judgements that can no longer be ignored in making decisions about water resources management. Explicit consideration will be required of the ethical and moral precepts that should govern both bio-physical and socio-economic analyses and the design of governance arrangements.

Greater need for consensus

All of these sustainable development concerns will be fertile ground for increased conflict and point to a greatly increased need for commitments to and governance arrangements for developing consensus and resolving conflicts.

Taken together these implications of sustainable development principles suggest a major increase in the difficulty of water resources management. In shaping a new consensus on water management principles, the CWRA must explore these and other issues as they arise in the specific context of different basins, examine how they are being dealt with presently, and suggest new initiatives that might begin to address them more effectively.

WHAT IS NEEDED?

An interrelated set of new initiatives will likely be required. However, it is important to note that in some cases they are only 'new' in that they would result in purported principles and policies actually being put into practice (*e.g.*, adequate funding to operate referral mechanisms or enforcement of existing permit requirements). In other instances, they are 'new' in that they implement ideas that are well established in the literature but as yet have not been fully utilized (*e.g.*, water pricing or regional residuals management). On still other occasions, they are 'new' in that they go much further than before (*e.g.*, in analyzing local river basin developments such as deforestation in terms of their global consequences or adopting more cautious strategies such as no-net-loss or net-gain of renewable resource productivity). In still other situations, they might be more truly 'new' in that they introduce novel ideas. While all new initiatives need to be undertaken as experiments in order to test their merits and refine them, some will involve more action than research and others more research than action.

The set of initiatives that need to be explored include new values, science, policies, and institutional arrangements. Below some of the questions that need to be considered in each of these realms are suggested.

New values

Fostering the changes in perceptions, attitudes and values that many commentators on sustainable development suggest have begun to happen will be critical in determining the context for the outcome and new initiatives in the management of water resources. Will people begin to have a greater appreciation of the essential interdependence of environmental, economic and social systems? Will a consensus form that reflects greater emphasis on the social and environmental ethics that condition economic development? What judgements will people make about the relative importance of social versus environmental ethics? Depending on the answers to these general questions, interest in and the results of specific initiatives in water resources management would vary greatly. Consideration therefore needs to be given to scenarios reflecting different assumptions about the nature and rate of change of perceptions, attitudes and values (*e.g.*, *status quo*, slow change and rapid change with regard to environmental, social and economic priorities). At the same time, consideration should be given to the specific initiatives related to water resource management in river basins that would encourage perceptions to change in particular ways (*e.g.*, pricing or rights mechanisms to create increased awareness of pollution and habitat damage cost).

New science

Meeting the growing diversifying demands for information about water in sustainable development when the resources for science are likely to continue to be highly constrained will necessitate much more strategic approaches to science. In assessing the advantages and disadvantages of expanding knowledge and ways to develop it, familiar questions will take on new urgency and forms: What bio-physical and socio-economic information could better inform decisions about the use of aquatic resources? To what extent does this require applied as opposed to basic research? Socio-economic versus bio-physical investigations? Where is descriptive knowledge the next priority? What functional knowledge is most urgently required? What should be the allocation of investigatory effort among inventory, monitoring, desk analysis, and experimental research? How can the exploding demands for interdisciplinary science and associated challenges of integrating analysis and synthesis across varied fields of knowledge and widely differing temporal and spatial scales be better met? What are the implications for education, training and re-training? These questions need to be addressed as they apply to the specifics of water in the sustainable development of different basins.

New policies

Pursuing sustainable development of water resources will require major changes in both substantive and procedural policies. The diverse policy questions raised by the evolving ethic are again familiar but have to be considered in a new and changing context of facts and values: Are there gaps in consideration of the water resource systems that can no longer be ignored (*e.g.*, groundwater and instream use)? Do resource objectives need to be reformed to reflect more conservative goals (*e.g.*, no-net-loss of productivity and zero discharge of toxic contaminants)? What are the interdependencies to be taken into account (*e.g.*, complementary economic development and water resource management policies)? Who should incur the costs and reap the benefits (*e.g.*, polluter or beneficiary pays)? At another policy level are the closely related policy questions concerning the means to be used in pursuing such ends: How should the methods and processes of impact assessment and planning be used (*e.g.*, project assessments developed and evaluated in the context of watershed plans)? What should be the reliance on market as opposed to regulatory mechanisms (*e.g.*, greater reliance on marketable rights)? What should be the role of citizen and interest groups in the management of resources (*e.g.*, contracts with groups to manage components of the resource)? How much should be invested in managing the resource and how should this be financed (*e.g.*, increasing and extending charges for water use)?

New institutional arrangements

Designing and implementing policies to reflect the evolving ethic of sustainable development will require institutional arrangements with the capability for unprecedented integration in water resources management. What are the reforms in institutional arrangements of governance that are necessitated by the evolving ethic (*e.g.*, increased utilization of market mechanisms, revision of substantive and procedural rights, greater reliance on self-determination, redefinition of the role of senior government)? In this context, what are the institutional arrangements for water that must facilitate the varied tasks of management: resource allocation, impact assessment, planning, enforcement, collection and research? Together the evolving ethics and functions of water management will create unprecedented demands for more productive arrangements for developing consensus and resolving conflicts. To meet these demands how should legislative, judicial, market and administrative mechanisms be redesigned to better serve their separate and joint governance purposes (*e.g.*, to obtain timely and appropriate decisions, how should legislative arrangements be

designed to create and redefine resource rights, judicial arrangements to adjudicate them, and market and administrative arrangements to reallocate them)? What are the improvements in the interactions skills of people involved in these institutional arrangements (*e.g.*, technical, communication, argumentation, negotiation and mediation skills)?

NEXT STEPS

It is proposed that the recently established CWRA Technical Bureau take the lead in addressing these questions and developing a consensus on sustainable development principles for water resources management in Canada. It would be particularly constructive if a draft statement of principles developed by the CWRA could be reviewed with other water professionals who are not members of the Association, such as the Society of Professional Biologists. Given the need to work with other sectors in sustainable development, it would also be valuable to consult with other closely related professional organizations, such as the Canadian Institute of Planners. Done well, the building of a new consensus on water management principles will greatly improve the likelihood of their implementation in the practice of sustainable development rather than languishing in textbooks and policy documents.

[1] **Previously published in *Water News* January 1992. 10(4). S1-S4.**

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Watershed Planning and Impact Assessment

CHAPTER 2

RESOLVING CONFLICTS AND COPING WITH UNCERTAINTY IN THE MANAGEMENT OF SUBSURFACE POLLUTION

Dan Walker

INTRODUCTION

The management of subsurface pollution is a frustrating and expensive task. A decade of experience with Superfund and similar legislation in the United States has yielded unsatisfactory results (Freeze and Cherry, 1989; Easterbrook, 1989; Adler, 1990; Travis and Doty, 1990; Stipp, 1991; Passell, 1991). The legislated goal of this effort is the permanent restoration of polluted sites through the removal of pollutants. However, such restoration now appears to be generally infeasible. The 'polluter-pay' principle has resulted in large expenditures of financial and technical resources in efforts to assign or avoid responsibility. Litigation and the threat of litigation dominate over scientific and engineering aspects. Despite the 'polluter-pay' philosophy, much of the expense is directly and indirectly passed on to society as a whole. The private and public costs have been on the order of tens of billions of dollars, and projected costs are on the order of one trillion dollars.

In Canada, the management of subsurface pollution is still evolving. It would be unfortunate for this country to simply adopt the flawed Superfund approach.

Research is needed to develop an improved approach to the management of subsurface pollution. This initiative requires an interdisciplinary effort, drawing upon the natural science of hydrogeology and the social science of negotiation studies. Central issues in this research are conflict resolution and coping with uncertainty. This paper addresses these issues. The need for an expanded view of negotiation in the management of subsurface pollution problems is outlined in the first part of this paper. This overview is followed by a discussion of remedial approaches highlighting hydraulic containment of pollution as an alternative to the removal of pollutants. The paper concludes with an examination of the role of modelling, negotiation processes, and technical alternatives.

EXPANDING THE SCOPE OF NEGOTIATION

This section presents a proposal for the expanded use of negotiations in the management of subsurface pollution, and suggests ways in which uncertainty can be handled in negotiated management.

Subsurface pollution, in common with most environmental problems, has a large potential for generating conflicts. Conflicts arise among all the parties involved: subsurface pollution regulators, the parties held to be responsible for pollution, past and present owners of polluted sites, insurance companies, creditors, groundwater quantity regulators, groundwater suppliers and users, interest groups, and people living in proximity to contaminated areas. These conflicts occur over questions such as: who is responsible for an occurrence of subsurface pollution; what remedial action should be taken; who should pay for such remedial action; and what compensation should be provided to parties who consider themselves to be adversely affected?

Negotiation as a method for resolving such environmental conflicts has been widely advocated and applied in the United States and Canada over the last two decades (Lake, 1980; O'Hare *et al.*, 1983; McCarthy and Shorett, 1984; Dorcey, 1986; Bingham, 1986; Susskind and Cruikshank, 1987; Crowfoot and Wondolleck, 1990.) The current management of subsurface pollution makes limited use of negotiation as an adjunct to regulation and litigation. For example, agreements for remedial action at individual polluted sites in the United States are often produced as a result of negotiations involving the regulatory agency and the responsible party(s) (Gilbert, 1989; Brennan and Frazier, 1991).

The potential benefits of such negotiations are limited by their narrow scope. Typically, the problem is larger than an individual site, and involves numerous other concerned parties. Narrow-scope negotiations therefore fail to resolve many of the conflicts, and fail to take advantage of potentially-beneficial options. Negotiations could profitably be expanded in both geographic and participatory scope. The benefits of such an expansion would include reduction of conflict through increased participation in a consensual process, and increased opportunities for cost-effective management. The latter benefit arises because management options with greater economies of cooperation and scale are associated with a broader scope of negotiation.

Expansion in geographic scope implies consideration of a larger area than a single polluted site. This point is important because parties outside the polluted site may be affected by it, or may be able to contribute to a solution. A larger geographic scope would also be advantageous in the management of non-point subsurface pollution, especially from agricultural sources. Ideally, the geographic scope would encompass an entire aquifer.

Expansion in participatory scope is linked to the expansion in geographic scope. Ideally, all parties who are affected by the problem, or may be able to aid in its solution, would be involved in negotiations.

There exists a range of possibilities, from the existing narrow-scope approach to a negotiated management plan covering an entire aquifer and all concerned parties. The latter would be the most comprehensive, the most difficult to achieve, and potentially the most beneficial.

Expanded negotiations would be best carried out according to the tenets of principled negotiation (Fisher and Ury, 1981; Fisher and Brown, 1988; Ury, 1991), with the procedural assistance of a mediator (Ozawa and Susskind, 1985; Bingham, 1986; Susskind and Cruikshank, 1987). The goal would be to obtain an agreement which would be beneficial for all parties: a win-win or integrative resolution (Fisher and Ury, 1981; Raiffa, 1982). Subsurface pollution problems have two characteristics which make them amenable to integrative resolutions. First, the cost of attempted removal of pollutants is so high that responsible parties have a strong incentive to find cost-effective alternatives, and a large pool of potential savings with which to pay for tradeoffs. Second, activities such as groundwater extraction exert a strong control on the flow of groundwater. This control can be amended in such a way as to restrict the transport of pollutants in the subsurface.

The expanded negotiation process is proposed as a complement rather than a replacement for the conventional procedures of regulation and litigation. It is clear that the party responsible for pollution has little incentive to take any remedial action in the absence of an adequate regulatory/litigative regime.

Uncertainty is a dominant factor in subsurface pollution problems. Information about the subsurface is usually expensive, often ambiguous, and always inadequate. Predictions about the behaviour of subsurface systems generally carry order-of-magnitude uncertainties. Uncertainties regarding the behaviour of the associated human systems are also significant.

Three suggestions can be made for coping with uncertainty in negotiated management: contingent agreements, experimental agreements, and renegotiation. The underlying philosophy in all cases is that surprises due to uncertainty are inevitable.

Contingent agreements are agreements of the form: "If event X occurs, then action A will be undertaken" (Raiffa, 1982; Susskind and Cruikshank, 1987). This approach appears to be a useful and fair mechanism for responding to surprise. It has the added advantage that it allows tradeoffs among different parties with different expectations of future events, and thus enhances the possibility of reaching agreement.

Experimental agreements are intended to test an option without fully implementing it (Ury, 1991). This purpose can be achieved by limiting the temporal and/or spatial scope of the agreement, and by including provisions for careful monitoring of the results. The concept of experimental agreement is compatible with Dorcey's (1986) concept of experimental management of natural resources.

Provision for renegotiation can be built into an agreement, on either a contingent or a periodic basis. Periodic renegotiation, perhaps on an annual basis, is appropriate to the long-term nature of subsurface pollution problems. It should provide a reasonable balance between flexibility and stability. It should enhance the prospects of reaching agreement, as the participants will be aware that they will not be locked into a long-term agreement with uncertain consequences. Over time, bargaining should become more efficient because the participants become familiar with the process and the knowledge base improves.

As an example, consider a hypothetical case in which a water supplier is concerned about pollution entering a water supply well from a nearby site. In a contingent agreement, the responsible party might agree to provide an alternate source of water for the water supplier in the event that pollution reaches the well. In an experimental agreement, the water supplier might agree to a temporary reduction in pumping rate at the supply well in order to determine if such an action could reduce or reverse the transport of pollutants from the site. In the case of renegotiation, the two parties could initially agree to monitor for pollution at observation wells, with provision to renegotiate whenever pollution was detected at an observation well.

HYDRAULIC CONTAINMENT

The most important opportunity for economies of cooperation and scale involves hydraulic containment: the dynamic restriction of pollutant migration by management of the hydraulic head. The discussion briefly outlines the concepts of hydraulic head and hydraulic containment. Readers are referred to Domenico and Schwartz (1990) for additional information. The opportunities for economies of cooperation and scale, and the implications for conflict reduction and coping with uncertainty conclude this section.

Hydraulic head at a point in the subsurface corresponds to the level to which water rises in a well which is open only at that point. One may think in terms of a hydraulic head surface which represents the hydraulic head at all points in a horizontal plane through the subsurface. The hydraulic head surface can be visualized as a time-varying 'topographic' surface, with two horizontal spatial dimensions and a third dimension representing hydraulic head. Groundwater flows 'downhill', or, more correctly, down the spatial gradient of the hydraulic head surface. The flow will be stagnant in 'flat' areas, and will be directed away from 'ridges' and 'hills'. Human activities can have a strong influence, intentional or otherwise, on the configuration of this hydraulic head surface. A local mound can be created by pumping water into a well, by allowing water to infiltrate into the subsurface from a pond or basin, or by increasing permeability at the surface and allowing increased infiltration of precipitation (*e.g.*, by building a landfill). A local depression can be created by pumping water out of a well, by planting vegetation, or by decreasing the permeability at the surface (*e.g.*, by emplacing a clay cap).

Subsurface pollution is primarily transported in the direction of groundwater flow. To implement hydraulic containment of subsurface pollution, one must alter the configuration of the hydraulic head surface to produce a local depression around the polluted zone. This depression defines a hydraulic containment zone. Containment is most commonly implemented by pumping to extract groundwater from within the hydraulic containment zone. Subsurface migration of pollutants will be restricted to the hydraulic containment zone, and the only exit points for pollutants will be the extraction wells. The extracted water can be treated to remove pollutants. Following treatment, it may be pumped into the subsurface at the boundary of the containment zone, so as enhance the containment. It should be emphasized that this is a long-term option which can take decades to complete.

Economies of cooperation and scale arise when it is possible, through negotiation, to coordinate hydraulic containment with other parties whose activities influence the configuration of the hydraulic head surface. This is referred to as 'coordinated hydraulic containment'.

Consider a hypothetical example in which a polluted site is surrounded by a number of water supply wells. The owners of the wells might agree to alter the pattern of groundwater extraction at the water supply wells so as to flatten the hydraulic head surface across the hydraulic containment zone. This alternative reduces the amount of pumping necessary to achieve containment. The party responsible for containment would agree to cover the cost of altering the groundwater usage pattern, and would benefit by the difference between this cost and the savings due to the reduction in pumping for containment. The well owners would benefit from the reduced risk of contamination.

Coordinated hydraulic containment has the potential to reduce some types of conflict associated with subsurface pollution. In particular, because it can reduce the costs of remedial action, it reduces the incentive for the responsible party to resist regulatory pressures.

But hydraulic containment does not resolve certain other conflicts, and may even exacerbate them. Communities in the vicinity of polluted sites typically have serious doubts regarding any remedial action short of the complete removal of pollutants. The appropriate forum for dealing with such doubts is the expanded-scope negotiation process, where options can be formulated to meet the community's concerns. A number of such options can be suggested. A possible tradeoff is the provision of alternative health benefits, such as venting of naturally-occurring radon gas from homes (Passell, 1991). Doubts concerning long-term commitment to containment could be addressed by the posting of a bond by the responsible party(s). Where local groundwater supplies are polluted or threatened, a convenient alternate water supply or appropriate water treatment equipment could be provided. Where exposure to polluted soil is a concern, fencing and capping could be installed and maintained. The costs of these various options would be covered by the responsible party(s) from the savings made available by not pursuing the removal option.

A major reduction in uncertainty is achieved by the shift in remedial goal from one of removal to containment. Removal requires detailed knowledge and predictions of the distribution and fate of pollutants in the subsurface. Containment requires only broad knowledge of the distribution of pollutants in the subsurface; the main knowledge and prediction requirements are with respect to hydraulic head. The measurement and prediction of uncertainties associated with the distribution of hydraulic head are much less than those associated with the distribution of pollutants. Furthermore, hydraulic head measurements are much less expensive to acquire than chemical analyses of subsurface samples.

MODELLING THE MANAGEMENT OF SUBSURFACE POLLUTION

In order to study these proposals, it is desirable to model the management of subsurface pollution for a hypothetical scenario. For this purpose, it is convenient to consider a subsurface pollution management system, consisting of two major subsystems: the hydrogeologic system and the conflict resolution system.

The hydrogeologic system encompasses a groundwater flow system, a pollutant transport system, and a remediation system. The remediation system comprises the various remedial activities such as removal and containment.

The conflict resolution system encompasses the parties who are affected by or concerned with subsurface pollution, and the conflict resolution methods which these parties utilize. The main forms of conflict resolution are regulation, litigation, and negotiation. The effective modelling of the subsurface pollution management system requires an understanding of both the hydrogeologic and conflict resolution systems.

Modelling the Hydrogeologic System

For the purposes of this study, the requirements for modelling the hydrogeologic system are computer models of groundwater flow, pollutant transport, optimization of hydraulic containment, and estimation of costs. The latter two represent the remediation system. The basic technical tool is a flow model which provides an estimate of the response of the hydraulic head surface to various disturbances, including human activities such as pumping.

Modelling of pollutant transport is not strictly necessary where hydraulic containment is the remedial option, but does provide useful information and understanding. Simplified transport modelling can be performed with a particle-tracking program, which traces the movement of particles along the flowlines generated by the flow model.

Modelling of hydraulic containment can be performed by linking a flow model with an optimization model (Maddock, 1972; Maddock, 1974; Gorelick, 1983). Optimization refers to a set of mathematical techniques which can provide an optimum management alternative from a set of decision variables. It allows evaluation of an objective as a function of decision variables, subject to various constraints. An example would be: "Minimize the deviation from a desired hydraulic containment scheme, where the decision variables are pumping rates at various locations, subject to the constraints of minimum pumping rates at certain locations and minimum hydraulic heads at certain locations".

The first step in optimization is to determine whether or not a feasible region exists in the decision variable space. It may be that the constraints preclude such a feasible region. This circumstance would indicate a need to relax some of the constraints, through negotiation, in order to produce a feasible region. In many situations, obtaining a feasible solution may be more important than obtaining an optimal solution. We might speak of 'feasibilization' rather than optimization. Cost estimation is an exercise in engineering economics. It can be assisted by an expert system tied in to a cost database.

Any modelling of real-world subsurface systems carries the important caveat of uncertainty. There exist large uncertainties in the input data, particularly with respect to the spatial distribution of system boundaries and parameters. These factors translate into difficulties with model construction and calibration, the need for expensive data collection, and large uncertainties in model output.

All of these modelling tasks can be performed with commercially-available software. The flow system can be simulated with MODFLOW (McDonald and Harbaugh, 1988), which is a standard finite-difference program for groundwater flow. The transport system can be simulated with MODPATH, a particle-tracking program which is used in conjunction with MODFLOW. Management of hydraulic head can be simulated with an optimization package such as LINDO which can be linked to MODFLOW using the program AQMAN (Lefkoff and Gorelick, 1987). Order-of-magnitude cost estimation can be obtained with the CORA software (CH2M Hill, 1990).

Modelling the Conflict Resolution System

Modelling the conflict resolution system presents a methodological challenge: how does one model the choices and actions of human beings? Two approaches are appropriate for consideration. The first utilizes the game-theoretic conflict analysis methodology of Fraser and Hipel (1984). The second utilizes gaming, in which human participants engage in a role-playing game (Greenblatt, 1988).

Conflict Analysis

Game theory is a mathematical abstraction of human conflict, competition, and cooperation (Myerson,1991). It is concerned with the optimal strategies for players (decision makers) who participate in a game (a situation involving at least two players) by making moves, subject to the rules of the game. Each move is a choice from a player's set of strategies. Each realization of a game results in an outcome, and each outcome is associated with a utility for each player. Utility refers to the quantitative, cardinal, real-number measurement of the 'goodness' of an outcome for a player. Players are assumed to be rational, implying that they act in such a way as to maximize their expected utility. An outcome which represents a possible resolution of the game is called an equilibrium.

Conflict analysis is a practical technique for applying game theory concepts to real-world situations (Fraser and Hipel, 1984; Hipel, 1990, 1991), based on the metagame theory of Howard (1971). A metagame is a game in which consideration is given to the reactions of a player to the known strategies of the other players. Metagame theory and conflict analysis reject the concept of utility. They are non-quantitative, and a player's preference function consists of an ordinal ranking of preferences rather than a cardinal utility function.

In conflict analysis, each player has a set of binary options. A binary option is an option which can be either selected or rejected by a player. A given choice of binary options comprises a player's strategy, and a player with k options has 2^k strategies. Combining one strategy from each player yields an outcome. A conflict with m options has 2^m possible outcomes. The outcomes are ranked for each player according to that player's preferences, yielding an ordinal preference vector. Unilateral improvements are determined from each outcome for each player. A unilateral improvement is a unilateral change in strategy which yields a second outcome which the player prefers to the original outcome. A unilateral improvement is said to be sanctioned when a second player could simultaneously or subsequently execute another unilateral improvement which would result in a third outcome which the first player prefers less than the original outcome. Stable outcomes are those which the player cannot avoid by executing an unsanctioned unilateral improvement. Outcomes which are stable for all players are equilibriums -- possible resolutions of the conflict.

Conflict analysis can be applied to the subsurface pollution management system on two levels. At the first level, the goal is to determine whether or not the parties will participate in negotiations (*e.g.*, Dagnino *et al.*, 1989). Each party has the binary option of negotiating or not negotiating, in addition to other conflict resolution options such as litigation. The second level assumes that negotiations have commenced. The analyst must generate various management options for each party. The parties also retain certain options which represent alternatives to agreement, such as litigation. The goal is to determine which set(s) of management options can result in agreement. The generation of options and ranking of preferences will require modelling of the hydrogeologic system. For some players, preferences may be established on the basis of expected monetary value. For other players, expected monetary value is an inappropriate criterion, and preference ranking will require the subjective judgement of the analyst. Conflict analysis can be implemented using the DECISIONMAKER program (Waterloo Engineering Software, 1989).

Role-Playing Games

Role-playing games are a legitimate tool for the study of public policy and for educational purposes (Greenblatt, 1988; Mautner-Markhof, 1989). They have been applied in a wide variety of fields, including business, public policy, and the management of environmental problems. They are often carried out in conjunction with computer modelling. There is an unfortunate semantic problem here: role-playing games should not be confused with game theory, or with the experiments which game theorists occasionally conduct with human subjects (*e.g.*, Raiffa, 1982).

The subsurface pollution game which is outlined below will function both as a research tool and as a training exercise. The training exercise would be intended both for students and for parties involved in a real-world subsurface pollution problem. The goal would be to improve competence in group decision making on subsurface pollution problems.

The following is a brief outline of the manner in which the subsurface pollution game might be played. The game manager would develop a hypothetical subsurface pollution system and assign roles, perhaps in consultation with the participants. The game would proceed through the following series of phases. Note that each phase is contingent on successful agreement in the previous phase.

(1) Prenegotiation: the players meet in an effort to determine if negotiations can be attempted.

(2) Procedural negotiation: the players meet in an effort to agree on process.

(3) Substantive negotiations on investigations: the participants meet in an effort to agree on joint investigations.

(4) Substantive negotiations on management actions: the participants meet in an effort to agree on joint management actions, after receiving information from the joint investigations.

(5) Substantive renegotiation: the participants meet again after one simulated 'year', to renegotiate the substantive agreements on the basis of new conditions and information.

The game manager would retain a set of 'perfect' information of the natural system. Some of this information would be provided to the players initially, and additional information would be provided to the players following agreement on joint investigations. The information provided to the players would be degraded in some fashion, in order to represent the uncertainties and imperfections which are inherent in any real-world information set.

The computer modelling of the hydrogeologic system would be carried out simultaneously with the game and would operate at two levels. The first level would be as a negotiation support system and aid the players in their efforts to reach agreement. It consists of the degraded and incomplete information set available to the players. The second level would be as a realization of the system's behaviour during the 'year' preceding the renegotiation phase, using the game manager's set of 'perfect' information. This realization would produce some unexpected results, necessitating renegotiation. These unexpected results would be due to two causes. The first cause would lie with the natural system, due to the variation between the players' information set and the 'perfect' information set. The second cause would lie in the human system, and would be generated by perturbing the set of management actions from those agreed upon (*i.e.*, by simulating imperfect implementation of the agreement).

SUMMARY

This article has presented two proposals for the improvements in the management of subsurface pollution: (1) expansion in the geographic and participatory scope of negotiations dealing with subsurface pollution; and (2) an emphasis on hydraulic containment of subsurface pollution, as opposed to the removal of pollutants. These proposals provide opportunities for coping with conflict and uncertainty.

An interdisciplinary methodology for studying these proposals has been outlined. This methodology involves modelling of a hypothetical subsurface pollution scenario. Both the hydrogeologic system and the conflict resolution system must be considered. The hydrogeologic modelling tasks are groundwater flow, pollutant transport, optimization of hydraulic containment, and cost estimation. Modelling of the conflict resolution system can be accomplished with either a game-theoretic approach, or with human participants in a role-playing game.

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CHAPTER 3

THE EVOLUTION OF INTEGRATED CATCHMENT MANAGEMENT IN WESTERN AUSTRALIA

Bruce Mitchell and Malcolm Hollick

INTRODUCTION

Integrated catchment management (ICM) was adopted as state Government policy in Western Australia (WA) on 30 November 1987. ICM focuses upon resolving land and water degradation by improving coordination of state agency policies and activities, and by increasing public involvement in the identification of problems and alternative solutions. The purpose of this paper is to identify the issues which led to the adoption of ICM, to outline its main characteristics, and to review the progress and problems which have been encountered during its implementation. In the conclusions, the implications of the experience with ICM in WA for resolution of conflicts and uncertainty are addressed.

BACKGROUND

The state of WA covers 2,525,500 square kilometres, or about one third of the Australian continent. In contrast, Ontario occupies 916,734 square kilometres. The population is about 1.5 million people, with over 1.1 million living in metropolitan Perth. Settlement is concentrated on the coastal plain in the southwest of the state, with only small centres elsewhere. Main economic activities include mining and agriculture, with agroforestry and tourism becoming increasingly important in the southwest.

ICM was developed to overcome degradation of land, water and other environmental resources in the state. This degradation cannot be halted by the actions of any single individual or organization, and there has been steadily growing pressure for effective action. The nature and extent of the problem have been documented by a parliamentary Select Committee into Land Conservation (1990a,b,c) and the Steering Committee for Research on Land Use and Water Supply (1989). The issues identified in the southwest of the state include:

- nearly 450,000 hectares, or 2.8% of cleared land, were affected by salinity in 1989, and there is potential for a further 5 or 6-fold increase;
- waterlogging affects production on about 2,000,000 hectares;
- nearly a quarter of agricultural land needed immediate treatment for wind erosion in the early 1980s, and a further 40% needed additional preventative measures;
- about 5 million hectares of agricultural soils are affected by water repellency which restricts the infiltration of rainfall;
- only 7% to 15% of native vegetation remains in the older agricultural areas, and remnant areas are declining throughout the region;
- many of the waterways are highly degraded by salinity, nutrient enrichment, loss of riverine habitat and fringing vegetation, siltation, and bank erosion;
- many wetlands have been lost since European settlement, and wetlands are inadequately represented in conservation reserves; and
- while 50% of the water resources are fresh and protected by forest, water salinity is increasing in catchments which have been partially cleared, and the major rivers have salinities too high for domestic water supply.

Shortly after adoption of the state policy, a national workshop on ICM was held in Melbourne (Australian Water Resources Council, 1988). At this workshop, the WA strategy was voted the best of all the state strategies, but it then had to be transformed into an operational program. It has been in the transition from planning to implementation that problems have been encountered.

IMPLEMENTATION

The WA Government's policy on ICM was adopted on 30 November 1987, but it was not until May 1989 that a policy booklet entitled "*Working Together*" was published. In it, the Government stated that ICM was to:

(1) include the coordinated planning, use and management of water, land, vegetation and other natural resources on a river or groundwater catchment basis;

(2) involve landowners and local communities at all stages from the identification of issues and problems in the particular catchment to planning and on-the-ground management; and,

(3) provide a streamlined "whole-of-government" approach to the complex and interconnected issues of balancing resource use and conservation.

The key was to be cooperative effort, with state government, local government, farmers, conservation groups and the community working together to solve existing problems and manage resources for the future. State authorities also would be encouraged to work towards common objectives by consultation, responsibility sharing and joint financing.

Several key decisions were made regarding implementation. First, it was decided that ICM would be realized through coordinating the policies and activities of **existing** agencies under **existing** statutes. No new legislation or agencies would be established. The rationale was that institutional arrangements in WA were not complex, and the public service was relatively small. On that basis, it was believed that the desired cooperation and coordination could be achieved by working within the existing system.

Second, a mechanism would be established to coordinate policies and activities, including formation of a Secretariat. And third, priorities would be set. It was in this context that implementation began.

The coordinating mechanism was an inter-departmental committee, initially called the Integrated Catchment Management Policy Group (ICMPG). Established in February 1988, the ICMPG included senior officers of various state government agencies but no non-government people. It answered to the Cabinet, and was chaired by a senior officer in the Department of Premier and Cabinet. This arrangement caused resentment among some Ministers and Chief Executive Officers who considered that it questioned their judgement and activities. A negative attitude toward the ICMPG developed in some key agencies, as reflected in the delegation of more junior officers to attend ICMPG meetings, and an unwillingness to consider sharing of traditional responsibilities or roles.

The original intention was for the ICMPG to coordinate rather than set policy. However, in "*Working Together*" it was stated that the ICMPG had been established "to develop detailed policies and co-ordinate the activities needed to put the policy into action". This statement in the policy document resulted in criticism by farmers' and environmental groups that the ICMPG was forming policy without public involvement or statutory accountability. As a result, in February 1990 the ICM Policy Group was renamed the ICM Coordinating Group, or ICMCG, to emphasize that it coordinated rather than made policy. At the same time, the ICMCG was made responsible to the Minister for the Environment rather than Cabinet.

The Secretariat for the ICMPG was created in May 1989, and was housed with the Secretariat for the Water Resources Council (WRC). The WRC is a statutory body with representation of both the community and government agencies which advises the Minister for Water Resources. The ICMPG Secretariat was funded by the WA Water Authority with secondment of an officer of the Water Authority. This arrangement caused problems for the ICMPG Secretariat. For example, the Executive Officer of the Water Resources Council believed that the ICMPG staff member should report to him regarding ICM and ICMPG matters. Yet at the same time, a senior officer in the Department of Premier and Cabinet had been given responsibility for ICM and ICMPG, and it was to this person that the ICMPG Secretariat was responsible.

In April 1990, the Office of Catchment Management (OCM) was created as the Secretariat for the ICMCG. This decision reflected several considerations. The Water Authority had decided that it would no longer fund the Secretariat. As a result, new funding was needed to staff it and provide new accommodation since the location in the Water Resources Council would not be tenable. Also, the incoming Premier decided to devolve activities such as the ICMCG from the Department of Premier and Cabinet in order to diffuse the resentment of Ministers and Chief Executive Officers toward groups which reported directly to the Premier's department. In May 1990, it was decided that the OCM would report to the Minister for the Environment, but would remain independent of state agencies responsible for land and water management, since a major role was to facilitate inter-agency coordination.

The OCM began to operate officially on 1 July 1990 with approval for 7 full-time staff. However, it actually had only 5 staff, including an executive director, a policy analyst, a catchment officer, an education extension person, and a secretary. It was not until August 1990 that the staff of OCM were all physically located in the same office.

Community Catchment Groups (CCG) began to be considered or established, particularly in coastal plain catchments of the south west. It quickly became apparent that clarification of their role and authority was necessary. Some CCG members expected the CCG's to become involved in making management decisions. In contrast, state agency officials usually viewed the CCG's as having an advisory role. Further difficulties arose because the relationships between the CCG's and other public groups, such as Land Conservation District Committees which worked with the Department of Agriculture, were left unspecified. It was intended that parallel Government Officers Technical Advisory Groups (GOTAG) also would be established to provide technical backup for the CCG's. In several instances, such technical groups were already in place, as they had been established to address pressing problems.

PROGRESS AND PROBLEMS

The introduction of ICM in WA was not a radical innovation. Various attempts had been made in the state since the 1970s to achieve coordination of state agency policies and activities, and to allow the public to become involved in environmental decisions (Hollick and Mitchell, 1991). Some of the issues encountered in implementing ICM had emerged earlier, while others were unique to ICM.

Defining Integrated Catchment Management

Integrated catchment management has been a vague and ambiguous concept despite publication of the "*Working Together*" policy statement and several pamphlets outlining the nature of ICM. This is understandable, since ICM is much like the concept of "sustainable development". Intuitively, most people can relate to the basic idea, but it is difficult to translate it into operational terms.

ICM has been presented as a **philosophy**, as a **process**, and as a **product**. The initial emphasis in WA was on developing the philosophy and the process for several reasons. First, in the long term one of the most important contributions of ICM is fostering an organizational culture and associated attitudes which view cooperation and collaboration as essential. Second, if ICM is to be effective, there needs to be a well understood process through which it can be delivered. Third, the product of ICM will vary from place to place, depending upon conditions and needs. It could range from a new process to development of guidelines or a plan. A key consideration in that regard was to differentiate any ICM catchment "plan" from the regional plans of the state Department of Planning and Urban Development and the environmental protection policies of the Environmental Protection Authority.

Development of a philosophy and a process for ICM was necessary and important. However, the relatively late attention given to defining a product contributed to a lack of understanding about objectives for ICM. Without tangible objectives or outputs, it was difficult to set directions, to establish the role of ICM relative to other programs and activities, and to monitor progress and effectiveness.

The Role of the Inter-Departmental Committee

The ICMCG has served as a forum for inter-agency coordination of policies and activities. It has had some notable successes. For example, it played a key role in developing a draft state wetlands policy, served as a forum to develop coordinated action for intensive horticulture on the Swan coastal plain and for remnant vegetation in the south west, and has functioned as a valuable clearing house for exchange of information about policies and programs of different agencies.

However, the ICMCG also has experienced problems. First, there has been uncertainty about the relative roles of ICMCG, the WA Water Resources Council and the new Soil and Land Conservation Council, which provide broadly-based advice to the Ministers for Water Resources and Agriculture, respectively. Second, there have been difficulties in setting the agenda of the ICMCG.

An inter-departmental committee can provide a mechanism to: (1) report on departmental activities and share information, (2) react to directives sent to it, (3) coordinate policies and activities, and/or (4) develop a vision for the future and explore means by which that vision might be achieved. The ICMCG has focused on the first of these for a variety of reasons. Some members argue that an emphasis on philosophy and process led to a loss of enthusiasm from some members, particularly operational agencies. Also, senior officials from some agencies did not attend the ICMCG meetings, making it difficult for strategic matters to be considered. Agencies were asked to suggest items for the agenda, but rarely did so. Also, agencies often did not complete reports which they had agreed to prepare for the ICMCG, so that strategic matters kept being postponed. Finally, when strategic issues were addressed, such as establishing priorities for policy coordination, some agencies became protective of their traditional roles and responsibilities. The result was that such issues were set aside, for fear that they would become disruptive and divisive.

The Role of the Secretariat

The OCM has had some notable successes. It played a key role in helping the Department of Planning and Urban Development and the Environmental Protection Authority to develop an approach through which regional plans and environmental protection policies can complement each other. The OCM had a central role in persuading state agencies not to define problems and develop solutions on their own, but to do this in consultation with those living in the areas of concern, and to consult with other state agencies through the ICMCG. It informed community groups about the opportunity to create Community Catchment Groups, and how to establish them. And OCM initiated the "Ribbons of Blue" program, which raises community awareness about water and land issues by having school children monitor water quality and develop action plans to tackle identified problems in their communities.

Problems also have been encountered. OCM was established initially for only 12 months, which is not sufficient for an organization to demonstrate its capabilities, particularly when many of its activities focus upon creating changes which only manifest themselves in the long term. OCM also received minimal financial support, with operating funds of only $25,000 (Australian) for the 1990-1991 financial year. As a result, there was almost no community or country work possible, publications were difficult, and there was virtually no consultancy or seeding money.

Criticisms also were levelled that the role of OCM was defined poorly, and it lacked a clearly developed program of activities. These perceived shortcomings arose from genuine differences of opinion as to the appropriate role of OCM. The key operational agencies (Department of Agriculture, Department of Conservation and Land Management, and Water Authority) wanted a Secretariat which was clearly a servant of the ICMCG and whose activities were determined and guided by it. Other agencies (Waterways Commission, Environmental Protection Authority) and the staff of the OCM saw the Secretariat's role as proactive and more independent. Under this model, the Secretariat would interact with community groups, and initiate activities without needing the sanction of the ICMCG.

A further complication was personality conflicts. The executive director of the OCM had been the senior official to whom the ICMPG had reported when it was accountable to the Department of Premier and Cabinet. Some of the resentment regarding that structure was directed at him as the visible symbol of the arrangement, and this was carried over when he became executive director of the OCM. The policy analyst in the OCM had been an employee of the Water Authority, and had been seconded to the ICMPG Secretariat when it was based in the Water Resources Council.

That individual challenged various attempts of the Water Authority to "control" the Secretariat, which caused friction. The friction continued when the same person became a staff person in the OCM.

The Role of Community Catchment Groups

The CCG's were not visualized in the state ICM policy released in 1989. At that time, the state government's position was that "integrated catchment management will build on existing opportunities for public involvement by ensuring that clear information is made available and by encouraging public feedback". Community groups such as Greening Australia, the Conservation Council and the Land Conservation District Committees (or Land Care Groups) were expected to "play a vital part in integrated catchment management".

As the ICM process evolved, a decision was taken to create CCG's in some catchments with representatives from community-based groups. This decision has facilitated the involvement of local people in defining problems and developing strategies. However, it also has created some uncertainty regarding the relative roles and responsibilities of CCG's, Land Care Groups, state line agencies, and local governments.

The Future

The need for ICM will continue because:

- land, water and related resources are still degrading;
- there are legitimate but different and often conflicting societal interests in those resources;
- relevant government policies sometimes conflict; and
- agency programs are not always complementary.

However, ICM may be perceived as threatening for several reasons. Some government Ministers and senior officials see it as a threat to traditional areas of responsibility and ways of conducting business, because it implies greater sharing, and sometimes a redefinition of roles. Some individuals and non-government organizations view ICM as a 'top down' process in which the State will impose regulations and other constraints, thus hindering local development. Some local government officials are uncomfortable because they do not understand how their responsibilities relate to ICM activities of state agencies and CCG's. Developers and development agencies worry that ICM will extend a planning and regulatory process which they already consider to take too long, and/or will create another layer of bureaucracy.

A review of ICM in WA was conducted during 1991 (Mitchell, 1991; Hollick and Mitchell, 1991). This assessment argued that there should be no radical changes, in the belief that an evolutionary approach would be more effective than a revolutionary one. However, it made a number of recommendations.

First, it suggested that the building blocks for ICM should be a: (1) systems approach, (2) an integrated rather than a comprehensive approach, (3) a stakeholder approach, (4) a partnership approach, and (5) a balanced approach. On this basis, it was recommended that the output of ICM should be a combination of philosophy, process and product. As a philosophy, ICM should result in a shift of organizational cultures and participant attitudes towards acceptance and pursuit of cooperative approaches. As a process, ICM should facilitate cooperation among state agencies, local governments and community groups. As a product, ICM should facilitate development of complementary regulatory instruments.

The review concluded that ICM must be given legitimacy and credibility through explicit political, administrative and financial commitment. Specifically, it was recommended that the state Government should publicly endorse ICM, release a revised ICM policy, and direct Chief Executive Officers of state agencies to include ICM as a key component in their corporate plans and programs. Furthermore, to facilitate budgeting, the ICMCG should establish a program for the next 3 years with estimated costs of specific tasks to be accomplished.

The review recommended that the ICMCG should continue, and that its members should be senior officers acting as the personal delegates of the Chief Executive Officers. However, the chair of the ICMCG should no longer be the executive director of the OCM, but should be rotated among member agencies, with each serving for 24 months. The ICMCG should have authority to create working groups which, while chaired by a member of the ICMCG, could include non-state agency people. The chairs of the ICMCG, the Water Resources Council and the Soil and Land Conservation Council should meet informally but regularly, and at least once a year there should a joint meeting of the two Councils in which the agenda would focus upon land and water issues of common interest.

An ICMCG needs the support of a Secretariat. There are advantages and disadvantages to attaching the Secretariat to an existing state agency or allowing it to operate at arm's length from them all. The review suggested that the Secretariat should be independent if it were to be viewed as "neutral". It then could provide traditional Secretariat functions, but also could be proactive. It was also suggested that the name of the Secretariat be changed from the Office of Catchment Management to the Office of Catchment Coordination, to emphasize that it is not an operational state agency but rather a facilitator of ICM.

It was recommended that the CCG's should continue as the principal mechanism of public involvement. However, the ICMCG should clarify: (1) the role, power and authority of the CCG's in the ICM planning and decision-making process, (2) the criteria for selecting members of CCG's, and (3) the financial support, if any, the state government would provide to CCG's.

The review was submitted to and considered by the three key Ministers involved (Environment, Agriculture/Water, Planning), and the appropriate Chief Executive Officers, as well as members of the ICMCG and the staff of OCM. While there was considerable agreement with the findings and recommendations, there were strong differences of opinion regarding the appropriate role of the Secretariat, its functions, and its degree of independence. The Minister for the Environment subsequently appointed a consultant to address these and other matters which emerged from the discussion following the review. In particular, the consultant had to find a way to resolve the personality clashes already discussed which would undermine the effectiveness of any system if they were allowed to continue.

At the time of writing (November 1991), most of the recommendations of the review had been accepted and were in the process of being implemented. However, a significant change is the decision to locate the OCM in the Waterways Commission (WC) rather than keeping it as an independent unit. The WC is a well-established but relatively small agency responsible for management of a number of estuaries. The Commission itself consists of an independent commissioner and the chairs of management authorities established for each estuary. Technical and professional support for the Commission and management authorities is provided by a small agency, also known as the Waterways Commission, headed by a Chief Executive Officer. In recent years, the WC has been called upon more and more often to assist local governments and communities in managing estuaries that are under threat but which have not been proclaimed under the *Act*, and for which no management authority has been established. Increasing concern is also being expressed for the state of the rivers in the south-west of WA, and it seems likely that the WC will eventually gain responsibility for managing all rivers in the region.

Since the management of the estuaries depends primarily on management of their catchments, the WC has always adopted a cooperative approach and a coordinating role in meeting its objectives, and has a natural interest in ICM. Thus, its organizational culture and responsibilities make it an obvious location for the OCM if the latter is to cease being an independent unit. The WC location also is acceptable to the major line agencies.

The decision will place the OCM under the administrative direction of the chief executive officer of the WC, but it will not be under the policy direction of the Commission itself. As part of the change, the OCM will become a permanent body under the 'protection' of an established agency, thus minimising the problems associated with its temporary status and vulnerability to budget cuts. The ICMCG will continue to exist, and will be chaired initially by the representative of the Department of Planning and Urban Development. This will free the executive director of OCM, who will continue in his position, to take a more active and independent role. A Cabinet Minute is to be issued instructing all relevant agencies to include ICM in their corporate plans.

DISCUSSION AND CONCLUSIONS

ICM in WA is similar to the comprehensive river basin planning conducted in Canada in the 1970s, and the adoption of an 'ecosystem approach' or 'integrated water management' in the 1980s and 1990s in places such as the Fraser River estuary, the South Saskatchewan River valley in Saskatoon, the Manitoba conservation districts, the Ontario conservation authorities, and the Toronto waterfront. In all these situations, planners and managers must deal with ongoing conflicts due to different values, interests, mandates and objectives. There also has been considerable uncertainty about commitment and financing. In this regard, the experience in WA has several implications for Canadians involved in integrated water management.

First, it confirms that there are no perfect solutions to addressing the legitimate but often different values and interests in society. All approaches have imperfections. The key is to develop an approach in which the various components complement each other and minimize each other's weaknesses.

Second, even if 'ideal' structures and processes are put in place, effective integrated water management requires people with dedication, good will and mutual trust to make it work. In WA, significant personality conflicts have hindered the implementation of ICM. Indeed, the conflicts were major enough that during 1991 modifications to the approach to ICM in WA addressed personality conflicts which were judged to be hindering the success of ICM.

Third, an integrated approach suggests a significantly different perspective - one requiring people and agencies to move out of their present 'comfort zones'. By definition, such a move creates discomfort. Thus, it can be expected that any move towards an integrated approach will include some turbulent and difficult times, and honest differences of opinion regarding the most appropriate way to proceed and to allocate scarce societal resources.

Fourth, if an integrated approach is to become a new ideal, there needs to be clarification as to what the ultimate end point should be. In WA, that end point is a situation in which the basic building blocks of ICM become part of the corporate culture of state and local government agencies. When that is achieved, much of the ICM infrastructure presently required could then be removed.

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CHAPTER 4

CREDIT RIVER WATER MANAGEMENT STRATEGY - PHASE II

Hazel Breton, David Maunder and William Snodgrass

INTRODUCTION

The Credit Valley Conservation Authority (CVCA) is currently developing a watershed plan for the long-term management of the water and environmental resources of the Credit River. A two-phase strategy is being used for developing the plan. Phase I concentrated on issues relating to water quantity, and was completed in 1990. Additional studies relating to terrestrial resources and land use planning issues will also be required to develop the plan. The second phase focuses on the identification and discussion of issues relating to water quality and natural resources, and integrates relevant aspects from the Phase I study.

The goals of Phase II are:

- to develop a practical, comprehensive and environmentally-sound management strategy for the environmental resources of the Credit River watershed; and
- to provide direction for subsequent subwatershed studies.

An ecosystem approach was taken to accomplish these goals. The issues were addressed at three different levels. These included:

Examination of Resources on a Watershed Basis

- this level will be of particular interest to provincial agencies such as the Ministry of Natural Resources or the Credit Valley Conservation Authority.

Evaluation of a Subwatershed

- the user group at this level would generally include Municipal and Regional governments and the conservation authority.

Integrated Evaluation of the Watershed

- the user group would be the conservation authority, Ministry of Natural Resources, and Ministry of the Environment.

STUDY AREA

The Credit River watershed encompasses land drained by the Credit River and its tributaries, including both the visible landscape, and the area underlying the surface in which groundwater flow occurs. The watershed drainage area is approximately 2,100 square kilometres. The main stem of the Credit River originates north of Orangeville and enters Lake Ontario some 68 kilometres further south. The Credit River has numerous tributaries, ranging in size from fourth order to second order streams.

Several key features of the watershed include:

- diverse land uses including urban, rural estate, agricultural, aggregate mining and landfill sites (25);
- three Sewage Treatment Plants (Acton, Orangeville, and Georgetown) located in headwater areas; and
- the reliance of the headwater municipalities on groundwater for water supply.

PRESENT STATUS AND FUTURE DEVELOPMENT

At present, the watershed is approximately 15 percent urbanized with a projected increase to approximately 35 to 40 percent within twenty years (2011). Urban and rural land uses contribute to the degradation of surface water quality, particularly in the lower reaches where significant urbanization has occurred. There has also been an impairment of the fishery as development has occurred, and a substantial loss of wetlands in the lower watershed. Furthermore, there is presently a significant concern about the quality and quantity of existing groundwater resources. However, recent practices, such as the reduction of phosphate levels in detergents and enhanced sewage treatment systems, have resulted in a significant lowering of phosphorus levels within the river over the last twenty years.

STUDY APPROACH

The study approach is divided into three parts. The first part reviews the nature of water and related natural resources (hereafter called environmental resources). Factors causing environmental degradation are noted. Key natural parameters influencing the distribution and quality of each resource are identified. Goals and objectives for each resource are also defined. The second section describes land use patterns and other human activities, and evaluates the nature and magnitude of their impact on the resources. The potential for mitigating these impacts is also assessed. This appraisal provides the foundation for the watershed management plan which is presented in the last section. Key components of the plan include the provision of a policy framework, development of an implementation strategy, and incorporation of monitoring programs.

ENVIRONMENTAL RESOURCES OF THE CREDIT RIVER WATERSHED

The Credit River watershed contains significant and diverse environmental resources including an important fishery, recreational areas, wetlands and wildlife habitat. In addition, significant landforms such as the Niagara Escarpment are located in the area. For the purposes of this study, the environmental resources (or constraints in the case of flooding or erosion) were categorized as follows:

- aquatic communities (including resident fisheries);
- natural features (*e.g.*, landforms, wetlands);
- recreation;
- aesthetics (both valley land and water related);
- groundwater;
- water quality;
- flooding; and
- erosion.

Aquatic communities, natural features, and recreation are outlined briefly to illustrate the character of natural resources in the watershed.

Aquatic Communities

The resident fishery was generally used as an indicator to define the quality of the aquatic communities. The upper watershed supports a self-sustaining coldwater fishery characterized by brook and brown trout. The middle watershed zone contains elements of self-sustaining (*e.g.*, rainbow trout) and non-self sustaining (*e.g.*, pacific salmon) coldwater communities, with pockets of warmwater (*e.g.*, largemouth bass) communities in impoundments and areas degraded by urbanization. The lower watershed contains elements of migratory coldwater, coolwater (*e.g.*, smallmouth bass) and tolerant (*e.g.*, blacknose dace) fish communities. Rainbow trout and Pacific Salmon are stocked in the lower Credit.

Natural Features

Natural features were defined to include:

- distinctive or unusual landforms;
- areas serving a significant hydrological function;
- critical wildlife habitat;
- areas containing provincially or regionally rare, or endangered plant species;
- areas containing undisturbed self-sustaining ecosystems; and
- areas of high aesthetic value in the context of the surrounding landscape.

As an indication of the significance of the existing natural features, CVCA has identified 49 Environmentally Significant Areas (ESAs) and 11 potential ESAs.

Recreation

The Credit River watershed is a major recreational destination for both watershed residents and residents of the Greater Metropolitan Toronto area. Key attractions to the area include the Niagara Escarpment and Bruce Trail, and sportfishing opportunities. Public recreational opportunities and facilities are operated by the province, the conservation authority, the municipalities, and the private sector. Major recreational activities include fishing, hiking and swimming. The CVCA owns and operates 13 Conservation Areas within the watershed.

POTENTIAL LAND USE IMPACTS

There are various ways in which existing or proposed land uses may impact the environment. For example, agricultural land use practices may adversely impact the environment as a result of:

- the release of high nutrient and pesticide loadings to the receiving streams during rainfall events; and
- cattle access to adjacent streams which may damage streambanks, and increase solids and bacterial loadings.

Urban land use practices may impact the environment due to:

- increased flows and pollutant loadings to the receiving streams;
- contamination of groundwater sources;
- toxic spills from industrial or commercial areas; and
- alteration of the existing natural features through the development of landfill sites, gravel pits or encroachment into the valleylands.

Several of the above noted land use practices may impact the environment in the short term (*i.e.*, a toxic spill which kills off or severely limits the resident fishery). Conversely, some impacts, such as contamination of a groundwater supply due to stormwater or septic system intrusion, may not be noticeable for several decades.

The following potential land use impacts were identified:

- existing and proposed urban development including construction activity;
- sewage treatment plants;
- agricultural runoff;

- waste disposal sites;
- water taking (surface and groundwater);
- aggregate activities;
- spills; and
- special land uses (*e.g.*, golf courses in valleylands).

ENVIRONMENTAL GOALS AND OBJECTIVES

A rigorous set of goals and objectives for each resource were established in consultation with the public, regulatory agencies, and special interest groups. An outline of established resource management goals is provided in Table 4.1. On a resource basis, more detailed goals and management objectives were established for the upper, middle, and lower reaches of the Credit River. As an example, an overview of goals and management objectives is provided for fishery resources of the Credit River.

GOALS AND MANAGEMENT OBJECTIVES FOR FISHERY RESOURCES OF THE CREDIT RIVER WATERSHED

UPPER REACHES

GOALS

- protection and enhancement of a high quality self-sustaining coldwater fishery in the Credit River and its coldwater tributaries
- enhancement of the warmwater sport fishery in Orangeville Reservoir
- protection of natural watercourses, water sources and supplies
- protection and enhancement of brook trout habitat

TABLE 4.1
Resource Management Goals for the Credit River Watershed

Surface Water

Maintain or restore water quality to a level which permits desired uses including safe drinking, ecological integrity, and recreation opportunities.

Groundwater

Protect and maintain groundwater recharge/discharge areas and baseflow to a level which ensures adequate supply for desired uses.

Fisheries

Protect and enhance aquatic communities, with special regard for fish and fish habitat.

Natural Features

Protect and maintain self-sustaining natural ecosystems and significant natural features.

Recreation

Provide diverse recreational opportunities that are in harmony with the environment.

OBJECTIVES

- develop performance standards (criteria) for the protection and enhancement of the coldwater fishery
- conduct technical studies to gain a quantitative understanding of key habitat requirements and population parameters of brook and brown trout (age and growth, population dynamics)
- conduct fisheries and habitat surveys in tributaries for which little is known of resident fish populations

MIDDLE REACHES

GOALS

- protection and enhancement of a high quality self-sustaining coldwater fishery in coldwater tributaries
- enhancement of migratory Atlantic salmon and rainbow trout habitat in the main stem of the Credit River
- protection of natural watercourses, water sources and supplies

OBJECTIVES

- conduct technical studies to gain a quantitative understanding of key habitat components and population parameters of resident and migratory species (age and growth, population dynamics)
- conduct fisheries and habitat surveys in tributaries for which little is known of resident fish populations
- develop performance standards (criteria) for the maintenance and enhancement of the coldwater fishery
- assist MNR in initiatives to develop self-sustaining Atlantic salmon population
- maintain passage for migratory species
- rehabilitate degraded tributaries

LOWER REACHES

GOALS

- protection and enhancement of warmwater fishery in the Credit River and its warmwater tributaries
- protection and enhancement of habitat for migratory salmonids
- protection and enhancement of nearshore Lake Ontario

OBJECTIVES

- rehabilitate degraded tributaries for warmwater fisheries
- improve water quality in degraded tributaries
- consider creation of fish habitat through new developments, redevelopment and abatement

FACTORS WHICH CHARACTERIZE THE QUALITY AND QUANTITY OF THE ENVIRONMENTAL RESOURCES

In order to protect an environmental resource, various conditions must be met. In some cases the factors impacting a resource may be defined directly. For example, the Ontario Ministry of the Environment "Blue Book" states that "a potential health hazard (to recreational activities) exists if the faecal coliform geometric mean density for a series of water samples exceeds 100 per 100 mL." Conversely, in order to protect a coldwater fishery various parameters, many of which are difficult to define, must be considered. Some of these include:

- appropriate stream morphology;

- adequate riparian canopy; and

- maintenance of baseflow and minimization of peak flow fluctuations during critical seasons.

Factors and their associated impact were identified for each resource. These parameters were then used to assess existing conditions and the potential impact of proposed land use changes.

QUANTITATIVE ASSESSMENT OF EXISTING AND FUTURE CONDITIONS

As was described previously, existing land uses or proposed land use changes may impact the environment in many ways. Outlined below is an overview of the quantitative assessment that was carried out in order to:

- define existing conditions; and
- establish the potential impact of proposed land use changes.

Prior to illustrating the existing or potential impacts, two simplified examples will be given.

The first example deals with the change in the hydrologic and hydrogeologic cycles. Table 4.2 illustrates the potential impact due to a land use change from a forested area to a typical single family residential area. The results show a marked decrease in infiltration, depression storage and interception storage. This decrease is balanced by a ten-fold increase in the volume of runoff which reaches the receiving stream.

Altering the hydrologic cycle impacts various environmental resources. For example, flooding and erosion potential are increased due to the increased volume of water. Wetlands are affected by a reduction in baseflow and water level fluctuations. Groundwater flow is changed due to a reduction of infiltration. Resident fisheries are influenced due to water level fluctuations, and reductions in baseflow and groundwater.

The second example compares typical urban runoff concentrations and sewage treatment plant (STP) effluent concentrations to Provincial Water Quality Objectives (PWQOs). PWQOs were established to provide direction as to acceptable water quality levels for various uses of water.

TABLE 4.2
Distribution of May to November Rainfall for Forested and Urban Areas

	FORESTED AREAS		URBAN AREAS WITH [illegible] IMPERVIOUS LAND			
			NO INFILTRATION		WITH INFILTRATION	
Item	Depth (mm)	% of Total Depth	Depth (mm)	% of Total Depth	Depth (mm)	% of Total Depth
May to November Rainfall	[illegible]	100	[illegible]	100	[illegible]	100
Interception Storage and Depression Storage On Impervious Areas	[illegible]	66.5	[illegible]	[illegible]	[illegible]	[illegible]
Infiltration	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Runoff	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Note: Sandy Soils Assumed

The comparison shows that urban runoff concentrations and STP effluent concentrations exceed PWQOs by a considerable amount (Table 4.3).

TABLE 4.3
Comparison of Pollutant Concentrations to Provincial Water Quality Objectives

Water Quality	Urban Runoff Concentration	WPCP Effluent Plant Concentration	Provincial Water Quality Objective
Parameter	(mg/L)	(mg/L)	(mg/L)
Suspended Solids	100	3.0	-
Total Phosphorus	0.33	0.35	0.03
Total Copper	0.035	0.014	0.005
Lead	0.14	0.02	0.03
Fecal Coliforms	25,000*	200*	100*

Notes: *Units of Fecal Coliforms measurement are "bacterial numbers": # counts/100 mL.

This assessment suggests that the pollutant loadings due to urbanization will increase substantially. Furthermore, significant mitigative measures will have to be undertaken if the Provincial Water Quality Objectives are to be reached.

A simplified spreadsheet analysis was carried out in order to define existing conditions, determine the major pollutant sources, and assess the impact of proposed land use changes. Flow components and water quality concentrations were determined for various conditions (*e.g.*, dry weather, wet weather) for each of the 19 subwatersheds.

In summary, the potential impacts due to proposed land use changes may be defined as follows:

- streamflow volumes, on an annual basis, will increase by up to 35 percent;
- surface runoff volumes will increase by 50 to 200 percent;
- baseflow and groundwater flow components will reduce considerably, especially in key headwater areas;
- the effluent from the Orangeville STP will, during dry weather conditions, account for more than half of the flows in the Credit River, downstream of Orangeville;
- suspended solids concentrations will not likely increase in the future due to the conversion of agricultural lands to urban developments;
- total phosphorous and total copper concentrations will exceed Provincial Water Quality Objectives by 2 to 6 times; and
- faecal coliform levels will exceed the guidelines for swimming by 3 to 20 times.

Several issues are evident from the study. First, past and present stormwater management practices for urban developments are inadequate to protect and enhance environmental resources. Second, all new developments must be accompanied with a set of best management practices (BMPs) and other mitigating measures sufficient to attain the resource goals laid out in this study. Third, the impacts of various land uses must be assessed and mitigative measures established. Fourth, retrofitting opportunities need to be pursued in existing rural and urban developments. Fifth, restoration of habitats for fisheries and other biota are required.

RESOURCE MANAGEMENT STRATEGIES

Past practices for many watersheds have focused on preventing or reducing problems associated with flooding and erosion. These programs have failed to protect the diversity and quality of the environmental resources (*e.g.*, wetlands, fisheries, groundwater quality) in southern Ontario. The development pressures within the Credit River watershed are significant. However, the present level of development (15 percent) within the middle and upper watershed is still relatively minor and significant resources do exist. Therefore, within the Credit River watershed, mitigative measures will include both remedial and proactive strategies.

Four resource management strategies were considered for the protection, enhancement and restoration of the existing resources. These included pollution prevention, pollution control, regulatory control, and land use policies/planning.

Pollution Prevention

Pollution prevention is an umbrella term for a wide range of source pollution reduction activities. These may include:

- public education - informing consumers on household hazardous wastes and lawn (*i.e.*, fertilizers and pesticides) management practices;

- source control - Sewer Use Bylaw Enforcement, spill prevention and management;

- inspection - regulatory inspection of erosion/sediment control devices; and
- alternative substance/material usage - replacement or substitution of non-hazardous for hazardous materials in processes.

Pollution Control

Pollution control generally involves the implementation of technical solutions to reduce/minimize the impact of a given source. A prime example is the construction or upgrading of a Sewage Treatment Plant to treat domestic and/or industrial sanitary effluent.

Regulatory Control

Regulatory control may be applied in one of many ways. For example, the Ministry of the Environment has various programs such as the Municipal Industrial Strategy for Abatement of Pollution (MISA). This program establishes guidelines for the discharge of pollutants from various municipal and industrial plants. Furthermore, regulatory control may be applied in conjunction with pollution control alternatives consistent with local water quality goals and objectives. For instance, this approach is used in the Region of Ottawa Carleton where proposed stormwater management facilities which discharge flows to the Rideau River must have effluent levels of faecal coliform (FC) levels less than 100 FC/100 mL. In this case, the loss of resource use (recreation-swimming) is of concern.

Land Use Policy

Land use policies may be formulated to ensure that various resources are protected. Various policies may be enforced to restrict specific land uses (*e.g.*, landfills, aggregate extraction) or to limit the level of development. Mitigative measures may be incorporated into development proposals. Furthermore, land use policies which protect key resources (*e.g.*, natural features, groundwater recharge and discharge areas) must be enforced. These resource strategies were used as a basis for developing the water management strategy.

PAST EXPERIENCE AND POLICY GAPS

Watershed plans were funded by the Ministry of Natural Resources and carried out by some conservation authorities in the early 1980s. Many of these plans were completed and subsequently abandoned. Some shortcomings included the lack of an implementation strategy, insufficient communication and input from peer agencies, too many recommendations, and failure to provide for effective watershed management.

In order to avoid these shortcomings, it was necessary to include all agencies with an interest in water management very early in the study. It was also necessary to identify the policy gaps which exist among agencies. The need for an efficient and coordinated plan review process for development plans would be in the interest of all agencies involved in water management. Municipal implementation through Official Plans and Secondary Plans would afford proactive protection and control of the natural features. This process must incorporate the need for subwatershed studies. Agricultural control programs (*e.g.*, Clean-up Rural Beaches Program) are also identified as having many benefits to the watershed. A program for the protection of headwater areas must be adopted in cooperation with the member municipalities if such areas are to continue to exist. The enforceability of sediment and erosion control needs to be clarified and appropriate measures taken. The protection of groundwater resources with the assistance of the Ministry of the Environment in identifying crucial aquifer recharge areas is as yet unexplored.

THE WATERSHED STRATEGY

The water management strategy was developed to provide direction for achieving long-term environmental goals and objectives. The basis of the protective and enhancement measures is outlined in Table 4.4. One of the implementation tools will be the completion of comprehensive subwatershed plans which will address concerns/issues identified in the water management

TABLE 4.4
Protective/Enhancement Strategy

- infiltrate an amount of stormwater where soils permit, equivalent to that under pre urbanization conditions, especially for tributaries containing coldwater fish species;
- provide water quality control ponds or equivalent technology on all other major urban discharges to achieve nutrient removal objectives for diffuse sources (stormsewer discharges) developed by the International Joint Commission (IJC) and co-signed by the Province of Ontario as a signatory upon the various water quality agreements;
- provide alternative BMPs to a wet pond on outlets discharging to a stream containing a resident coldwater fishery;
- provide spill control devices on all stormwater outlets prior to their discharging to water quality control ponds or infiltration devices, or to surface water streams;
- maintain canopy and baseflow in streams containing remnant populations of brook trout;
- create natural channels to allow for biotic life in streams in a manner which is consistent with the needs of property protection, erosion control, and flood control;
- educate the public to the requirements of a clean environment;
- offset the impact of increased runoff from future development through reforestation and wetland creation.
- set aside in all areas of new development, land for installing BMPs, if it is uncertain, which type of BMPs should be installed.

strategy. The study has identified 19 natural subwatersheds. A fact sheet has been developed for each subwatershed and information on a variety of subjects (*e.g.*, resources/constraints, sources of contamination, key issues) is provided.

At present, the CVCA is in the process of reviewing and refining an implementation strategy. Questions on how the strategy can be implemented into the existing framework and hierarchy, who should be involved, what changes will have to be made as well as ensuring the appropriate updates are made, are being considered by the conservation authority in conjunction with the steering committee.

It is evident from the study results that past and present practices cannot be relied upon if the goals and objectives for the Credit River and tributaries are to be met. Therefore changes in direction using new and improved practices will be made. Such practices would include promoting infiltration, providing water quality ponds, encouraging natural channel designs, habitat enhancement, educating the public and taking advantage of reforestation and wetland re-creation opportunities to address overall water budget issues.

THE IMPLEMENTATION STRATEGY AND MONITORING

Although not completely formulated at this point in time, the implementation strategy will include, but not limited to the construction of urban best management practices, retrofitting existing ponds, stream rehabilitation and addressing agricultural runoff, aggregate extraction, and landfill sites (proposed and existing). Some of the more proactive approaches include land use policies, land use control, development of memos of understanding among the regulatory agencies, completion of subwatershed plans and sewer use bylaws. It is hoped that such mechanisms will offer protection to the natural resources of the watershed.

In order to assess the success of the water management strategy in meeting the goals and objectives, mechanisms for environmental monitoring will be required. This will offer a sound basis from which to detect environmental changes over space and time. It will also be a useful tool for identifying environmental cause-effect relationships and remedial actions. The basic components will be water quality and quantity, groundwater, habitat, ecology and toxicity.

CHAPTER 5

WATER LEVEL CONFLICTS AND UNCERTAINTY ON THE GREAT LAKES

Doug Cuthbert

INTRODUCTION

Lake Superior riparians do not want their lake used as a water storage reservoir that is subjected to widely fluctuating water levels as dictated by downstream interests! Some property owners on the shorelines of Lakes Huron, Michigan and Erie believe their shoreline erosion and property damages are caused by excessively high lake levels and are demanding the 'benefits' of lake level regulation on these lakes! Lake Ontario riparians do not understand what caused the excessively high lake levels of the spring of 1991 and low levels of the fall of the same year! Members of the recreational boating community on the upper St. Lawrence River believe that the flow regulators botched their job in 1991, and are complaining vehemently about low river levels! In the late fall of 1991, Montreal harbour water levels dropped below chart datum causing commercial navigation problems and economic losses!

These are a few of the many conflicts centred on fluctuating water levels and flows in the Great Lakes-St. Lawrence River system. Many interest groups which are affected by fluctuating water levels also experience varying levels of uncertainty on the question of what will water levels be next month, or next year, and how should they plan their actions that are linked to these water levels.

BACKGROUND

During the 20th century, water levels on the Great Lakes have fluctuated over the ranges of 1.1, 1.8, 1.9, and 2.0 meters respectively on Lakes Superior, Michigan-Huron, Erie and Ontario (Figure 5.1). Excessively high lake levels were experienced during the years 1929-30, 1952, 1973-74, and most recently in 1985-86. Low lake levels were an issue in 1925, 1934-35 and 1963-64.

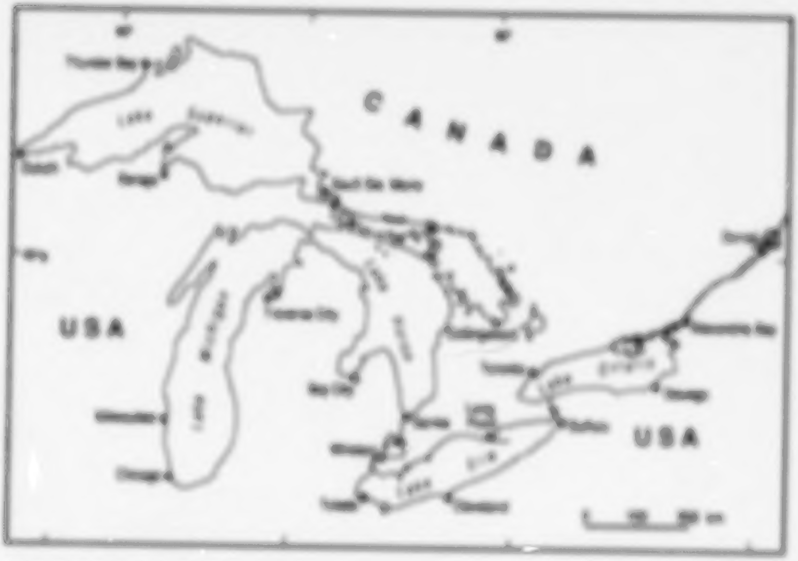

FIGURE 5.1. The Great Lakes

Variation in water supply to the lakes due to trends in regional precipitation is the cause of fluctuating lake levels. Annual cycles in lake levels caused by regular within-the-year variations in water supplies are superimposed on longer-term and irregular trends in lake levels driven by often small but persistent climatic variations. The very large storage volume and surface area of the Great Lakes, which represents about one-third of the watershed area, buffers short-term variations in water supply. Therefore, a month or two of extremely dry or wet conditions, or even one dry or wet year may not cause unusually high or low lake levels. But a number of successive wet or dry years will cause lake levels to rise or fall to levels that cause basin-wide concern among the many adversely-affected interest groups.

Human influences in the form of dams, diversions, deforestation and development in the watershed have some effect on lake levels. The effects of some of these individual activities are measurable but are often overstated by those who do not understand the nature of the system. In some cases, people are looking for an agency or scapegoat to blame for their misfortune. Those agencies which operate the control dams and diversions, such as government departments, and hydropower and commercial navigation corporations, are often blamed for extreme lake levels. The measured or reported effects on lake levels due to human activities in the watershed are summarized in Table 5.1.

A number of technical investigations of lake levels have been conducted over the years in response to agency and public concern. Each of these investigations was precipitated by a period of extreme high or low lake levels. Record high levels particularly as they affected Lake Ontario in 1952 led to a review by an Ontario Select Committee (1953).

Prior to 1952, the literature contains a number of references to fluctuating lake levels problems and proposed solutions. One of these was *The Campbell Plan for the Restoration of the Great Lakes Water Levels* (Last, 1923). This report suggested that the "low lake level problem" could be solved by constructing a sixth "Great New Lake" north of Lake Superior in the Albany River headwaters. This alternative would have seen the diversion of Hudson Bay tributary waters through Lake Nipigon into Lake Superior.

A very comprehensive 1926 report entitled *Regulation of the Great Lakes* (Freeman, 1926) examined the Chicago Diversion issue as it contributed to the then low lake levels, and described regulatory works that could be operated to raise the levels of Lakes Michigan-Huron and Erie. At that time, a dam was already in place at the outlet of Lake Superior and engineering works in the St. Lawrence River were being considered.

Since the Ontario Select Committee investigation of 1952, the St. Lawrence Seaway Project was constructed by, and primarily to serve commercial shipping and hydropower interests; U.S. Supreme Court limits

TABLE 5.1
Incremental Effects of Artificial Factors Affecting Great Lakes Levels

Factors Affecting Lake Levels	Superior	Michigan -Huron	Erie	Ontario
Major Diversions	+0.3	+0.1	-0.3	+0.1
Superior Regulation	0	0	0	0
Ontario Regulation	0	0	0	-0.3
Erie Outlet Changes	0	+0.1	+0.4	0
Channel Dredging	0	-1.3	0	0
Cumulative Total	+0.3	-1.1	+0.1	-0.2

Notes: (1) Levels are measured in feet as affecting average lake levels. (2) The effects of consumptive uses, deforestation, land drainage and tributary regulation throughout the watershed have not been accurately defined. Consumptive use of water will cause a small but increasingly significant reduction in lake levels. Land use modifications are considered to change the timing of and lead to higher run-off rates.

Reference: Project Management Team, July 1989

were placed on the volume of water redirected out of the Great Lakes by the Chicago Diversion; the Grand Canal scheme to divert James Bay tributary waters to the Great Lakes was proposed in similar fashion to the Campbell Plan of 1925; and four International Joint Commission (IJC) Reference studies on water level issues have been initiated by the Canadian and U.S. governments.

The first of these IJC Reference studies was begun in 1964. Concerns over the record low lake levels of 1963-64 caused governments to request that the IJC investigate "measures within the Great Lakes Basin that can be taken in the public interest to regulate further the levels of the Great Lakes". The report (International Great Lakes Levels Board, 1973) was completed after nine years of innovative and thorough investigations. The recommendations contained in this report, combined with the extensive shoreline damage experienced during the high lake levels period of the early 1970s, resulted in a 1977 request by governments to the IJC to conduct two additional lake level studies. The Lake Erie Regulation Study Board was asked to "undertake a study to determine the possibilities for limited regulation of Lake Erie" (International Lake Erie Regulation Study Board, 1981). The Great Lakes Diversions and Consumptive Uses Study Board (1981) was asked "to examine and report upon the effects of existing and proposed diversions within, into or out of the Great Lakes Basin, and the effects of consumptive uses on Great Lakes levels and flows".

Although these three IJC studies led to some minor changes in the Lake Superior regulation plan, all were consistent in their conclusions that further regulation of lake levels by means of outlet control dams or manipulation of diversions was not an effective measure to address the problems associated with fluctuating lake levels.

Most recently, the public outcry over high lake levels of 1985-86, particularly from the well organized International Great Lakes Coalition of shoreline property owners led to the current Government Reference to the IJC "to examine and report upon methods of alleviating the adverse consequences of fluctuating water levels in the Great Lakes-St.Lawrence River Basin" (Project Management Team, 1989).

THE CURRENT 1986-93 GREAT LAKES-ST. LAWRENCE RIVER WATER LEVEL REFERENCE STUDY

The current Lake Levels Reference study has three components: (1) an interim investigation and report (International Joint Commission, October 1988) focusing on emergency actions and measures that could be implemented within approximately one year or less to alleviate the then critically high lake level related problems; (2) a Phase I investigation over the period April 1987 to January 1989 which culminated in a progress report

(Project Management Team, 1989) to the Commission; and (3) the current *Phase II* study from mid-1990 to a projected completion in March 1993.

Prior IJC studies relied heavily on Canadian and U.S. federal government staff and resources, and to a small degree provincial/state representation. Some 'outside' expertise was contracted but the work was done primarily by government agencies and staff. Since many individuals did not support the recommendation of previous studies which rejected further regulation of the lakes, the Commission appointed an unprecedented number of non-federal members to the Phase I project Management Team and functional groups. Of the five Phase I functional or working groups, only one - Hydraulics, Hydrology and Climate was led by government staff. The other four were led by academic experts, consultants, or IJC Commissioners and staff. Despite this unprecedented infusion of outside expertise and viewpoint, the Phase I findings did not support further lake levels regulation. This recommendation was severely criticized by pro-lake regulation interest groups.

The IJC responded to these comments by disbanding the Phase I Project Management Team and appointing a new eleven-member Study Board only two of whom are from federal government agencies. The efforts of this Phase II Team are supplemented by a Citizen Advisory Committee and four topic-oriented Working Committees. Through this structure, the Commission has been very successful in involving representatives of the Great Lakes states, provinces and ten identified interest groups throughout the entire study.

The members of the Study Board and Citizen Advisory Committee, listed in Tables 5.2 and 5.3, devised a planning process that incorporated citizen's concerns and public interest group involvement unlike previous investigations. On the one hand, public involvement has been so extensive that concerns have been raised by some technical and agency representatives that the study has been slanted and driven towards the pro-lake regulation faction. On the other hand, criticism of the study has been directed at too much effort and resources being directed at examining land use and management measures to the detriment of system-wide lake regulation measures. One of the conflicts at the top of the list of Phase II discussion items is land use management versus lake level regulation measures. Other conflicts which have been discussed during the process include the following:

TABLE 5.2
Phase II Study Board Members and Affiliation

	Affiliation	Interest Group
Canada		
Tony Wagner (Co-chair)	Environment Canada	federal government
Andre Harvey	Environnement Quebec	provincial government
Maurice Lewis	Ontario Natural Resources	provincial government
Philip Weller*	Great Lakes United	environmentalist
Peter Yeomans*	Maire de Dorval	municipal government
United States		
John D'Aniello (Co-chair)	U.S. Corps of Engineers	federal government
Joseph Hoffman	Pennsylvania Water Resources	state government
Kent Lokkesmoe	Minnesota Natural Resources	state government
Clifford Sasfy II*	Int'l Great Lakes Coalition	riparian
Frederick Brown*	retired	environmentalist
Ned Fulton	Study Director	private contractor

* denotes Board members who are also Citizen Advisory Committee members

(1) The decision of governments not to build new water-level control dams and the previous studies that have not supported system-wide lake levels regulation is a source of conflict. The position of the International Shoreline Coalition is that regulatory and other engineering works should be constructed to reduce the range of levels on the 'unregulated' lakes, and that once begun (*i.e.*, control dams do exist at the outlets of Lakes Superior and Ontario), the job should be finished with control dams built at the outlets of Lakes Huron and Erie.

(2) The 'environmental' viewpoint on the construction of lake level control facilities appears to be directly opposed to that of the Coalition. Wetland, wildlife and other environmental groups support adaptive rather than engineering approaches to resource use, and do not agree with the construction of structures that would significantly change the level and flow regime of the Great Lakes.

(3) A number of individual shoreline property owners and businesses perceive that their lake level-related problems are the responsibility of governments to resolve and that economic hardships associated

TABLE 5.3
Phase II Study Citizen Advisory Committee Members

	AFFILIATION	INTEREST GROUP
CANADA		
Philip Weller (Co-chair)	Great Lakes United	environmentalist
Jean Eaton	Ontario Hydro	hydropower
Alexander Harry Q.C.	Harry & Rowand Law Office	riparian/local gov't
Sharon Hearn	Int'l Great Lakes Coalition	riparian
Christiane Simard	Union Québécoise pour la conservation de la nature	environmentalist
Larry Hamilton		recreational boating
Peter Yeomans	Mairie de Dorval	municipal government
Michael Williams	Walpole Isl. Heritage Centre	native people
Edith Potter		municipal government
UNITED STATES		
Clifford Sasfy (Co-chair)	Int'l Great Lakes Coalition	riparian
Frederick Brown		environmentalist
Richard Moore	Michigan United Cons. Clubs	environmentalist
John R. Sullivan Jr.	City of Oswego	municipal government
Henry Hanka	Duluth Port Authority	shipping
Joe Milauckas	Int'l Great Lakes Coalition	riparian
David Bohmann	Int'l Great Lakes Coalition	riparian
Howard Reynolds	Keweenaw Bay Community	native people
Dick True	Empire State Marine Trades	recreational boating

with fluctuating levels should be borne, at least in part, by government or 'big business'.

(4) Typical 'upstream-downstream' conflicts are apparent even within similar interest groups. Many in the recreational boating community on the upper St. Lawrence River support additional structures in and downstream of the Thousand Islands area in order to maintain levels throughout the boating season. Yet, this same group does not want the St. Lawrence River used as a conduit to resolve upstream water level problems as would be the case if major lake regulation measures were to be implemented. At the top end of the system, Lake Superior shoreline interests do not want their lake to be treated as a reservoir to be used for water storage or as a source of water to mitigate downstream water level problems.

(5) The views of some members of the International Great Lakes Coalition are expressed in often very strong and aggressive terms.

The Coalition publishes a newsletter containing articles, editorials, and letters on lake level-related news and activity. Two recent editions of this newsletter contained editorials and articles blasting the IJC's Phase II study, its government contributors, and environmental concerns that are being raised related to lake level regulation. The term 'environmental fanaticism' is being used indiscriminately! Views and actions that do not support lake level regulation are being heavily criticized.

(6) Environmental concerns about lake level regulation and engineering solutions are being stated just as strongly. The resulting polarization of views poses problems and challenges for effective communication and constructive discussions among participants.

(7) Global warming and climate change brings a considerable degree of uncertainty to the lake levels question. Are we currently experiencing a long-term climatic trend leading to higher or lower lake levels? What about increased short-term variability in water supplies and storm conditions attributable to climate change? Current scientific projections of global warming indicate a strong future potential for decreased lake levels, but its timing and extent are uncertain.

(8) Many of the industries in the region including hydropower, commercial navigation and tourism can be detrimentally affected by extreme lake levels. They appear to be more concerned with the unpredictable and uncertain nature of lake level and flow extremes than by the fluctuations themselves, although they are also affected by extreme levels.

(9) The Phase II study addresses other issues which are cloaked in uncertainty. Can lake level fluctuations actually be limited to a range of two feet or less? If lake level variations are kept acceptably low, will flows and water levels in interconnecting channels be suitable? Will reductions in lake level fluctuations actually result in reduced shoreline erosion?

(10) Semantics is a cause of uncertainty and conflict. Terms such as 'past damages', 'future costs avoided', and 'shoreline erosion versus

flood damage' mean different things among members of the study team.

(11) And finally, in the uncertainty category, it is probably fair to say that members of the IJC, the Phase II Study Board and its various committees as well as many of the lake level interest groups are all a little uncertain at the present time regarding the report's final outcome and recommendations!!

POTENTIAL FOR RESOLUTION OF GREAT LAKES WATER LEVEL CONFLICTS AND UNCERTAINTIES

Everyone who becomes involved with this Great Lakes issue probably wonders at times whether it is possible to ever resolve the conflicts and uncertainties. Many lake level-related uncertainties have been or are now being reduced in number and scope. For example, objective and acceptable ranges of lake levels for many pro-lake regulation groups are better defined and understood than ever before. From Lake Superior (no increase in current maximum or average levels - possible reductions in average or lower levels); through Lake Erie (reduced highs and lows and a narrowing of the levels range from 1.9 meters to less than 1.0 meter); to the St. Lawrence (maintenance of a much narrower range of levels on the river); the threshold of acceptable versus unacceptable lake levels for many riparians and shoreline property owners is being defined.

The ability of current lake levels regulation facilities to modulate fluctuating lake levels is being better understood by all interest groups. Existing lake level regulation plans are being examined and modified wherever possible to be more responsive to current lake level interests. Potential new lake levels control dams and the substantial specifications required to further modify lake levels to the degree desired by the Great Lakes Coalition are being defined. In addition, their effect on levels and flows throughout the system and related impacts on all other interests are being identified.

Other adjustments and variables are also being examined on both a short- and long-term basis. Land use management measures and their effectiveness are being described and evaluated in detail. The potential impacts of global warming on lake levels are being better defined.

Alternatives to adjust to these circumstances are also being assessed. Better weather forecasting used in combination with wave and storm surge models provide a much improved ability to predict the occurrence and impact of severe storms on the lakes. Storm warnings of several hours to several days can be transmitted through sophisticated communications networks, and decisions made to minimize the threat to lives and property.

A heightened awareness of the extent and magnitude flooding and shoreline erosion increases the support to minimize danger to lives and damage to property. Perhaps above all, the Phase II study is developing a clear understanding of the range of concerns, the identification of threshold levels beyond which interests have not, are not willing to, or cannot adapt to. Information is being made widely available on every aspect of the Phase II study. Descriptions of watershed responses to possible measures and climatic variation are being prepared for all those who are participating in the study or wish to become familiar with the study results.

The Phase II Board has made the study more open than ever before through regular mailings of a newsletter and summaries of work to a list of more than 3,000 Canadians and Americans around the lakes. By March 1993, 17 public meetings will have been held from Duluth to Montreal.

Some conflicts still exist and may remain unresolved. For example, some residents may feel that a proposed solution ineffectively addresses their concerns. These individuals may continue to be at odds with the present investigation. But solutions will be defined for all to understand and choose from. Methods of evaluating these measures will be discussed and probably debated at length in a fully open and public forum.

Hopefully, by means of the unprecedented involvement of a wide range of interests in the IJC's Phase II Levels Study, each participant will gain an understanding and appreciation of other views. Through this understanding and perhaps a shared decision-making process, a consensus view of the range of measures and actions to deal effectively with problems associated with fluctuating Great Lakes levels can be cultivated.

The ultimate test will be the survival and effectiveness of the results and recommendations of the Phase II study through the next period of extreme high or low water levels on the Great Lakes-St. Lawrence system.

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CHAPTER 6

ENVIRONMENTAL ASSESSMENT OF THE MERRICKVILLE HYDROELECTRIC STATION

M.S. Yu and D.A. Chubbuck

INTRODUCTION

In 1990, Ontario Hydro initiated a Small Hydraulic Assessment and Retrofit Program (SHARP) to renew its small hydroelectric stations in order to continue to provide electricity in a reliable and environmentally sound manner. The program is to be carried out over a 20-year period, ending in 2010. Under SHARP, a small hydroelectric station is defined as one in which the individual generating units have a capacity of 10 Megawatts (MW) or less. Out of the 68 Ontario Hydro owned hydraulic generating stations, 33 would be renewed under SHARP. The average age of these small stations is 75 years, with the youngest being 69 years and the oldest being 97 years.

Most of these small stations are reaching the end of their service lives, and their performance and conditions have deteriorated. For each station, a condition assessment is carried out. This report examines the existing condition and the remaining life of the structure as well as the mechanical, electrical, protection, and control equipment in the powerhouse and associated facilities. This assessment is used to determine what further work is required for the station.

Merrickville is the first hydroelectric station proposed for modification under SHARP. It is located on the Rideau River in the United Counties of Leeds and Grenville in eastern Ontario (Figure 6.1). In 1990, a condition assessment of the Merrickville Generating Station (GS) identified the need for modifying the station. The assessment included technical and financial evaluations of all aspects of the generating facility: structure, equipment, water availability, and potential power and energy production.

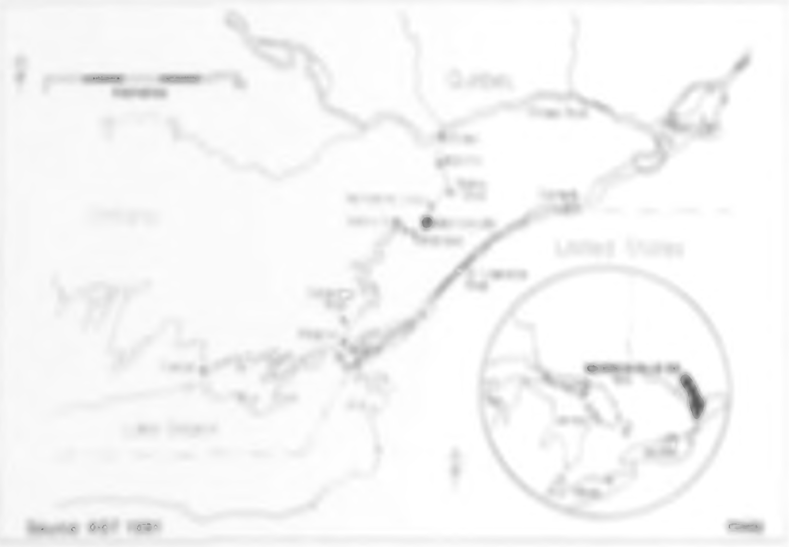

FIGURE 6.1. Merrickville Hydroelectric Generating Station (GS): Regional context

The proposed station modification is subject to the *Ontario Environmental Assessment Act* (EA) under the provisions of Ontario Hydro's Class Environmental Assessment for Modifications to Hydroelectric Facilities. Because the generating station is located on federal property, the Canadian Parks Service-Rideau Canal (the initiating federal department), reviewed the project under the Federal Environmental Assessment and Review Process (EARP). The Class EA planning process was followed by Ontario Hydro to assess the environmental effects of the proposed project and its alternatives. Ontario Hydro has prepared an Environmental Report describing the results of the planning process which was submitted to the Ontario Ministry of the Environment and the Canadian Parks Service.

This paper presents an overview of the existing and proposed generation facilities at Merrickville, and discusses a number of key environmental assessment issues which were raised and addressed during the Class EA planning process. It also identifies proposals to reduce potentially negative effects of station modification on the natural environment and resource users.

DESCRIPTION OF THE EXISTING GENERATING STATION AND OPERATION

Merrickville GS was constructed between 1914 and 1919 by the Rideau Power Company. There are two generating units in the station, with a total installed capacity of 750 kW. The station has headworks, two penstocks and a powerhouse. In 1949, the facility was acquired by the Hydro-Electric Power Commission of Ontario (now Ontario Hydro).

The existing generating station operates as a 'run-of-the-river' installation utilizing up to 16 m³/s of flow at maximum output. Water is conveyed beneath Mill Street from the headworks to the powerhouse by two 19 m long 2.4 m diameter steel penstocks (Figure 6.2). Adjacent to the station on the north side, is a stoplog sluiceway (No. 3) that is operated and maintained by Canadian Parks Service.

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FIGURE 6.2 Merrickville Hydroelectric Generating Station and nearby features

The Canadian Parks Service owns and controls the various facilities used to regulate water levels and flows in the Rideau River and Canal system. These facilities including Sluiceways Nos. 1, 2 and 3 at Merrickville are operated by Rideau Canal personnel. The water levels in the Rideau River downstream of Merrickville are controlled by Clowes Lock No. 20 located approximately 3.5 km downstream of Merrickville. During the navigation season (mid-May to mid-October), the water levels in this reach are maintained at elevations between 95.25 and 95.30 m. During the remainder of the year, these levels are maintained between 94.95 and 95.00 m.

Water levels upstream of the station are also controlled for the principal purpose of navigation. Analysis of historical headpond water levels indicated that the average annual upstream water level is 102.86 m, varying from a high of 102.96 m in August/September to a low of 102.75 m in January/February. The headpond at Merrickville does not have a large storage capacity.

In the tailrace channel downstream of the station, the overall range of total flows in the past (i.e., discharges from the station and spills from Sluiceway No. 3) on an annual basis has ranged from a minimum of zero to an estimated maximum of 34 m³/s. The minimum condition would occur in a dry summer when all available flows are used to support navigation; this may be an intermittent and short-term condition. The maximum condition would be typical of the spring freshet when the station would be at maximum output.

THE PROPOSED STATION MODIFICATION AND ALTERNATIVES

After reviewing a number of alternatives in renewing Merrickville GS, the modification of the facility is proposed for the following reasons:

(1) to ensure continued safe operation of the Merrickville GS;

(2) to make improved use of the available hydroelectric potential at Merrickville; and

(3) to reduce present and future operation and maintenance costs.

The proposed project involves the modification of portions of the existing powerhouse (internal floors, roof and rear wall height) and the intake structure (installation of a headgate). The existing generating units and electrical, mechanical and protection and control equipment will be replaced with new equipment within the existing powerhouse (Figure 6.2). The intake, penstocks, powerhouse and tailrace channel will be retained, with repairs to concrete and upgrading for continued safety.

Temporary construction facilities will include a short access road to the tailrace area, a construction office, parking and laydown areas, and a tailrace cofferdam. The construction period is expected to last 12 months, and is tentatively scheduled from June 1993 to May 1994 (subject to gaining all necessary approvals). The construction program has been scheduled to minimize the effect of construction activities on the recreational users of the area. All construction work, except for mechanical and electrical work, will mostly be carried out inside the powerhouse and not scheduled during the tourist period. Work in the water is restricted to the non-navigation season as much as possible.

After modification, the total installed capacity of the station will increase from 750 kW to 1,800 kW. The modified station will continue to be a 'run-of-the-river' operation. No changes in flow requirements or headpond levels are required to accommodate the modified station. Flows through the station will be increased under the new operating regime following station modification. This increase would be within the present discharges experienced in the tailrace channel which is up to the value of 34 m^3/s. Historically, the total discharges at the channel have consisted of 16 m^3/s through the existing turbines at full power and about 19 m^3/s through Sluiceway No. 3. Tailwater levels are controlled within prescribed limits by Canadian Parks Service, and any fluctuations in tailwater level should be consistent with past experience.

A number of alternatives for carrying out station modifications were evaluated and compared prior to the selection of the preferred alternative. These alternatives relate to powerhouse design, tailrace channel improvement, turbine-generator equipment design, and powerhouse access.

The environmental comparison of these alternatives is described in Table 6.1. Of particular interest to the Village of Merrickville, the Canadian Parks Service, and the Ontario Ministry of Culture and Communications are the alternatives involving the powerhouse design and access.

Powerhouse Design Alternative

Two powerhouse design alternatives were considered: a new powerhouse, and the retention of the original powerhouse with efforts to minimize changes to the outward appearance.

Given the age and condition of the existing building, and the small internal area available to install modern efficient equipment, the first modification option is to construct a completely new facility. This alternative involves the removal of the powerhouse and its replacement with a new building. The new powerhouse, housing two units, would be larger than the existing building. Retention and repair of the existing intake, headworks, and penstocks would complete the new generating facilities.

The second station design alternative is to retain the original powerhouse facade and replace the generating equipment. Engineering studies have found that to accommodate most designs of modern efficient turbine generators, a draft tube extension is required, which slightly alters the appearance of the powerhouse downstream wall at and below the waterline. In order to accommodate a powerhouse crane, the roof must be converted to a flat design from the present gently sloping design. The downstream wall will be extended upward about 1 m to the new roof level.

As discussed in the following section, the concern was expressed by the Canadian Parks Service and local heritage associations for the preservation of the powerhouse and minimization of alterations to the external station. The alternative of retaining the powerhouse was selected as the preferred alternative which is in keeping with the concern for the heritage value of the station. Figure 6.3 illustrates an artist's rendition of the existing and modified stations.

TABLE 6.1
Merrickville GS
Environmental Comparison of Alternative Methods

Alternative Methods	Advantages	Disadvantages	Selection of Preferred Alternative Methods
POWERHOUSE DESIGN			
New Powerhouse	Period of employment will be longer	Noise from general construction activities over longer period of time More frequent disruption to Hwy. 43 and extend longer period of time Noise and traffic interference with tourism will be longer Changes to external facade of powerhouse	
Retention of Powerhouse	Modification may result in some employment of local residents for period of months Historical value of existing brickwork facade will be maintained for the most part		PREFERRED ALTERNATIVE - least changes to powerhouse appearance and short-term noise and traffic impact
TAILRACE CHANNEL IMPROVEMENT			
Excavation to Deepen Tailrace		Excavated sediment, high in copper and oil/grease, would require landfill disposal and the excavation may impact fishery habitat downstream. There is also no clear economic benefit for deepening the tailrace channel	
No Excavation	No disturbance of sediment at tailrace. Minimal impact on aquatic habitat		PREFERRED ALTERNATIVE - least impact on aquatic habitat
TYPE OF GENERATING UNITS			
Two Double Francis in Pressure Casing units, installed capacity 1800 kW	Minimal changes to the existing powerhouse exterior and substructure		PREFERRED ALTERNATIVE - changes to the existing powerhouse exterior and substructure are minimized

TABLE 6.1
Merrickville GS
Environmental Comparison of Alternative Methods (cont'd)

Alternative Methods	Advantages	Disadvantages	Selection of Preferred Alternative Methods
POWERHOUSE ACCESS			
Access Through Industrial Heritage Park		Vegetation would have to be removed to build an access road from Highway 43 to the tailrace at the foot of the power station Disruption to the use of the park by residents/tourists, and a temporary reduction in the aesthetic appeal of the park area	
Access through driveway running east from Mill Street on the north side of the foundry located on the north side of the station	This route least interferes with the public or residential sectors and is closer to available land needed to support construction activities. Space is available from nearby property owners for construction laydown areas, construction facilities space and equipment work space with minimal removal of vegetation		PREFERRED ALTERNATIVE - least disruption to local traffic and businesses and impact on heritage park
Access through Rideau Street which runs through a residential area into the second marina downstream of the station		The tailrace would be accessed via a route through the second marina into the first marina and lastly through the foundry, thus disrupting the marina businesses and residential area	

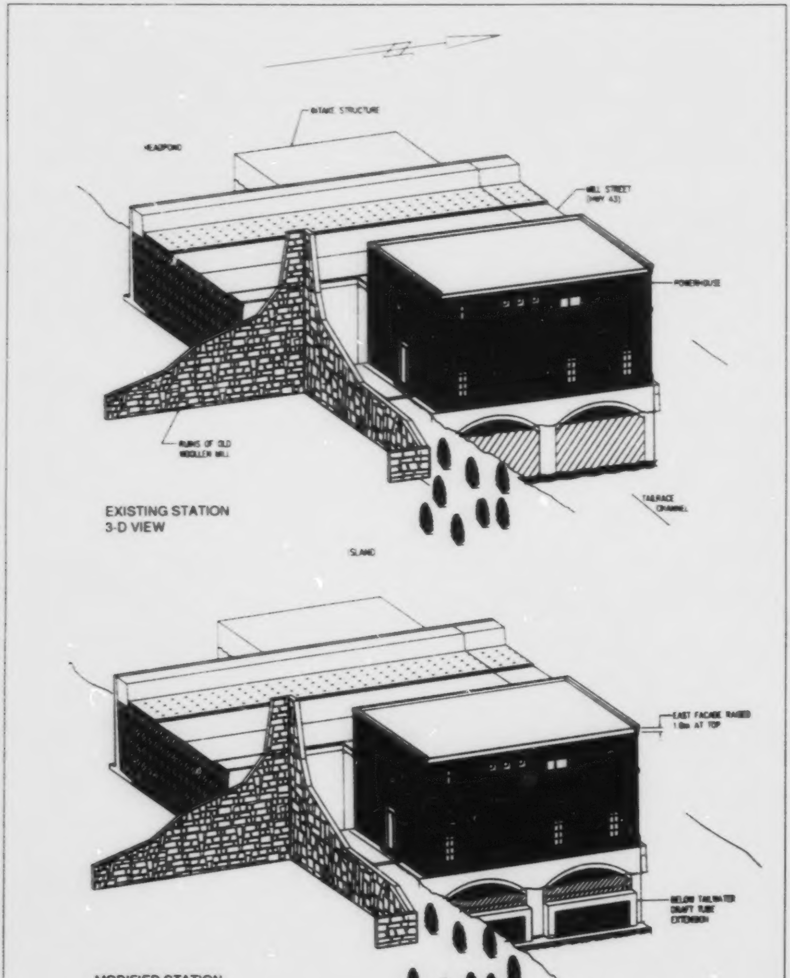
N
INTAKE STRUCTURE
HEADPOND
MILL STREET (HWY 43)
POWERHOUSE
RUINS OF OLD WOOLLEN MILL
TAILRACE CHANNEL
EXISTING STATION
3-D VIEW
ISLAND
EAST FACADE RAISED 1.0m AT TOP
BELOW TAILWATER DRAFT TUBE EXTENSION
MODIFIED STATION
3-D VIEW
05480

FIGURE 6.3. Merrickville GS powerhouse exterior 3-D view existing and modified station

Construction Access to Powerhouse

In considering access alternatives to the powerhouse, it is recognized that partial or complete blockage of Mill Street (Highway 43) for truck unloading or for construction activities should be kept to a minimum to facilitate traffic flows.

Three access alternatives were identified. The first alternative involves access to the tailrace area through the industrial heritage park (located on the south side of the powerhouse), combined with access through the powerhouse roof (after removal) using cranes stationed in the tailrace area (refer to Figure 6.2). The second access route involves use of the driveway running east from Mill Street on the north side of the foundry (located on the north side of the Merrickville GS site) and a subsequent routing through the foundry property to the tailrace area east of the powerhouse, again using cranes stationed in the tailrace area. The third access route involves the use of Rideau Street (first street north of the foundry) which runs through a residential area into the second marina downstream of the station. The tailrace would be accessed via a route through the second marina into the first marina and lastly through the foundry.

Considering the effects on the environment and resource uses, the access road through the foundry area is preferred over access through the industrial heritage park or use of Rideau Street. The preferred route least interferes with the public or residential sectors and is closer to available land needed to support construction activities. Space is available from nearby property owners for construction laydown areas, construction facilities space and equipment work space, and agreement has been reached with the owners.

PROJECT SETTING

The Rideau River watershed has a drainage area of 4,095 km^2. Approximately 127 km in length, it flows easterly from its headwaters in Burridge Lake and eventually north to its confluence with the Ottawa River. Water levels and flows in the Rideau River system are controlled by the Canadian Parks Service.

The Rideau River supports a warm water fish community that includes northern pike, walleye, muskellunge and bass as the important sport fish. No commercial fishery exists on the Rideau River at the present time. Both upstream and downstream of the Merrickville station, brown bullhead is the dominant species caught in this area. Pumpkinseed, black crappie, largemouth bass, rock bass, northern pike and yellow perch are also found in the river. Walleye, a highly valued sports fish, was found in small numbers downstream of Merrickville and in even smaller numbers in the catch upstream. The tailrace area of Merrickville GS is considered to be degraded as fish habitat and does not appear to be heavily used by popular sport fish such as walleye.

Since the Merrickville GS is located in an urbanized setting, the terrestrial environment has been greatly modified by human activities. Only those plant and animal species cultivated by humans or highly tolerant of industrial and recreational activities are expected in the immediate area of the station. The wetland adjacent to Merrickville station is a minor part of the extensive wetlands which border the shoreline of the Rideau River system. Downstream of Merrickville, a 6 ha wetland is considered as an important songbird nesting and fish spawning and nursery area. The second, much larger wetland area (133 ha) is found approximately 1.5 km upstream of Merrickville.

Tourism is a seasonal economic activity in the Merrickville area. The Village of Merrickville has an attractive ambience which appears to be very much in demand as part of driving tours originating in Ottawa, 75 km away. Part of this ambience is found in the Rideau River and Canal which form the basis for the area's recreational (boating and fishing) activities, as well as associated heritage facilities. Over 2,600 vessels used the locks at Merrickville during the 1990 season, and the most use is in July and August. Heritage- and recreation-related activities such as boating, fishing, interpretive centre and cottage industry remain important components of the community.

ENVIRONMENTAL ASSESSMENT ISSUES EFFECTS AND MITIGATION

Potential project effects were identified through environmental baseline studies, field surveys and investigations and consultation with government representatives (federal and provincial), local officials, interest groups and members of the public. Public and government involvement programs were conducted to ensure issues were identified fully and considered in the assessment. Through meetings, scoping exercises, site tours, discussions, participation in a community fair and reviews of the project and draft Environmental Report, efforts were made to obtain a clear and comprehensive understanding of public and government concerns, and to the extent possible, to resolve those concerns.

In determining environmental effects of the project, potential sources of effects during station construction and operation on the natural environment, resource use and the socio-economic environment were defined. These concerns related to site access, site preparation, cofferdam and temporary flow diversions, construction of facilities, project employment, project-generated economic activity, and in-migration and presence of construction workforce. A number of environmental assessment issues were identified during the Class EA process. Tables 6.2 and 6.3 summarize the environmental issues and effects of Merrickville GS during construction and operation, respectively. In eliminating and reducing environmental effects to an acceptable level, mitigation measures were proposed and described in Tables 6.2 and 6.3. A few comments on the key issues raised by government agencies and the public are offered as follows.

The heritage value of the powerhouse and mechanical equipment was raised by the Canadian Parks Service and the local historical groups at Merrickville. It was indicated that the station is located among a collection of buildings within a highly significant industrial heritage site. The heritage landscape near the Merrickville station is an important factor in the consideration of the heritage importance of the facility. The Canadian Parks Service indicated that preference should be given to the preservation of historic buildings rather than the rebuilding of a site to the previous design.

TABLE 6.2
Summary of Environmental Issues and Effects of Merrickville GS Modification During Construction

Resource Feature	Environmental Issue	Construction Effect	Mitigation/Management Feature
AIR QUALITY & NOISE			
Noise	Equipment operation	Localized and short-term noise from equipment operation	Heavy equipment operation will be limited to daytime hours during the peak tourist season (late May-early October), equipment will be properly muffled
Air Quality	Equipment operation emission	Localized and short-term effects of equipment emissions and equipment travel on dirt road	All equipment will be required to adhere to relevant guidelines for emission control Dust suppressants and dust covers on trucks will prevent dust problem
AQUATIC ECOSYSTEM			
Fisheries	Cofferdam installation and dewatering activities at tailrace will affect on fish and aquatic habitat	Dewatering of tailrace will result in minimal and short-term displacement of habitat	Cofferdam will be installed and removed outside fish spawning period (April-June) Stranded fish will be captured and returned to river
Water Quality	Surface water runoff, spill control and sedimentation and contamination from excavated materials at the tailrace	Minor and short-term effects	Design and placement techniques, use of cofferdams, sedimentation control facilities and spill contingency plans Excavated materials will be analyzed for contaminants and disposed of in an MOE-designated disposal site
TERRESTRIAL ECOSYSTEM			
Wildlife	Loss of wildlife habitat due to minor clearing adjacent to the access road, parking and laydown areas	Minimal and temporary loss of wildlife habitat	Laydown and parking areas sited in existing disturbed area with low wildlife population levels to minimize potential of habitat loss
Vegetation	Vegetation clearing along the banks of the tailrace and adjacent to the access road, laydown and parking areas	Minimal and short-term effects	Any topsoil to be disturbed will be stripped and stored for future use in site rehabilitation. Cleared areas will be landscaped and revegetated as soon as practicable following completion of construction

TABLE 6.2
Summary of Environmental Issues and Effects of Merrickville GS Modification During Construction (cont'd)

Resource Feature	Environmental Issue	Construction Effect	Mitigation/Management Feature
RESOURCE USE			
Recreation & Tourism	Effects on heritage park user to enjoy the tailrace area and their safety Disruption of traffic on Hwy #43 and traffic safety	Minimal and temporary effects	Fencing will be provided along the southern bank of the tailrace, around the intake and on the west side of the powerhouse to ensure the safety of the public as well as limit off right-of-way construction equipment movement, eg. on the heritage park. Traffic delays will be minimized and flagpersons used to direct traffic and ensure traffic safety.
HERITAGE RESOURCES			
Old Generating Equipment with Heritage Value	Loss of heritage resources	Potential for permanent loss of heritage resources	Existing old equipments will be offered to a museum for historical display purposes. Photo documentation of equipment before removal.
Archaeological Resources	Loss of archaeological resources	Potential for permanent loss of archaeological resources	Canadian Parks Service archaeologist will conduct a test pit survey along the affected shoreline prior to construction.
SOCIO-ECONOMIC ENVIRONMENT			
Transportation	Heavy truck traffic will wear down existing road structure - Hwy #43 Traffic disruption with village bi-centennial events	Potential damage to roadwork, traffic disruption	Trucks will be subject to load restrictions and traffic regulations. The Village will be provided with a detailed schedule prior to construction.

TABLE 6.3
Summary of Environmental Issues and Effects of Merrickville GS Modification During Operation

Resource Feature	Environmental Issue	Operation Effects	Mitigation/Management Feature
AIR QUALITY & NOISE			
Noise	Noise generated by turbine and transformer at the modified station	Noise effects to station nearby vicinity	Noise levels will comply with the Ontario Hydro and MOE guidelines
AQUATIC ECOSYSTEM			
Fisheries	Fish entrainment from increased planned average flow through turbine	Potential increase in fish entrainment	Newer improved turbines may minimize cavitation and be more efficient, thus facilitating fish passage and reducing fish injury and mortality
TERRESTRIAL ECOSYSTEM			
Wildlife	Potential wildlife loss	No adverse effects on local wildlife are predicted	None
RESOURCE USE			
Aesthetic	Aesthetic enjoyment of the station and heritage park by the tourists and local residence	Minimal visual impact	The area around the station will be restored to its original state including revegetation of the tailrace banks. Visual integrity of the station will be retained by maintaining the historical ambience in the local area

As discussed previously, alternative ways of modifying the Merrickville GS were evaluated. The concern over the heritage value of the facility was an overriding factor in the selection of the preferred alternative which minimizes alteration to the station and maintains the external appearance.

The concern of using Mill Street to access the station during construction was expressed by a number of government agencies and the Village of Merrickville. The disruption of traffic along Mill Street during tourist season should be minimized. A number of access alternatives to the powerhouse were investigated and the preferred alternative of carrying out most of the construction from the downstream side of the powerhouse was selected to minimize traffic disruption. Any use of Mill Street for loading or off-loading will be accommodated in the parking area in front of the powerhouse.

The effects of increased flows through the station in the tailrace channel following modification and potential implications to the operation of the marinas downstream of the powerhouse were discussed with the marina owners and the Canadian Parks Service. Based on the analysis of the historical record of flows and water levels, the increased discharges at the station would not exceed the flows which have been historically experienced at the tailrace channel and Sluiceway No. 3.

As discussed in the following section, post-operational monitoring is proposed to periodically record flows through the powerhouse and the three sluiceways, and identify potential problems of bank erosion.

As part of the Class EA process, Ontario Hydro identified a number of measures to eliminate or minimize potentially adverse environmental effects. Most of the mitigation measures proposed for the Merrickville GS modification relate to construction effects (Table 6.2). Some of the key mitigation measures are described as follows.

Atmospheric Aquatic and Terrestrial Environment

All construction equipment will be required to adhere to relevant guidelines for emission control, and noise will be controlled by applying to

Ontario Hydro's policy guidelines. Environmental acceptable dust suppressants such as water will be used as necessary. Heavy equipment operation will be limited to daytime hours during the peak tourist season (late May to early October), unless extenuating circumstances require otherwise.

The cofferdam will be installed and removed outside of the April-June period to minimize the effects on spawning fish. Prior to the completion of the dewatering activity, any stranded fish will be captured and returned to the river. Equipment service areas will be kept as far from the river edges as possible, at least 15 m, and on relatively flat ground. Fuel tanks, refuelling areas, sites for equipment servicing, and any chemical storage areas will be located within a dyked area on flat terrain, also at a distance from the river.

Vegetation clearing along the banks of the tailrace and adjacent to the access road, laydown and parking areas will be minimized. Areas that are not to be used as permanent facilities will be landscaped and revegetated as soon as practicable following completion of construction.

Resource Use

Fencing will be placed along the south bank of the tailrace, around the intake and along the west side of the powerhouse to ensure the safety of the public and limit off right-of-way movement by equipment and staff. Traffic delays will be minimized, especially on Mill Street, and flagpersons will be used to direct traffic and ensure traffic safety.

Heritage Resources

If possible, the turbine-generator equipment will be moved to a museum for historical display. If excavation along the bank of the tailrace channel is required, a test pit survey will be conducted along the affected shoreline by an archaeologist.

A pre- and post-monitoring program is proposed by Ontario Hydro to demonstrate compliance with the commitments made in the Environmental Report and any conditions placed by regulatory agencies. This program is also intended to identify the need for additional mitigative or compensatory actions required to protect the natural and socio-economic environments and heritage resources, and to determine the effectiveness of proposed mitigation measures. The general components of the monitoring program include: dust, water quality, traffic, revegetation and restoration, flows through the powerhouse and sluiceways, water levels in the tailrace area, and tailrace bank erosion.

CONCLUSIONS

The Class Environmental Assessment Process concludes that the Merrickville GS Modification is the preferred alternative to renew and enhance the hydroelectric generating potential of the existing generating facility. Opportunities were provided for input from government agencies in the scoping of field studies, the identification of effects, selection of mitigation measures and the review of the Environmental Report. Through meetings, discussions and the community fair, efforts were made to discuss the proposed project with the public and develop a common understanding of their concerns. This public and government interaction has, and will continue to be, a major influence on the decisions relating to the implementation of this project.

The existing Merrickville Generating Station has served a long and useful purpose. Through modifications, the power output of the station will be extended and enhanced. This proposed project will provide a benefit to the electricity consumers of Ontario. It will also continue to enhance the attractiveness of the local areas for tourism and recreation. The construction of the project will provide some employment opportunities to workers in the region.

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CHAPTER 7

THE MATTAGAMI RIVER EXTENSIONS HYDROELECTRIC STATION: ENVIRONMENTAL ASSESSMENT ISSUES AND EFFECTS

R.R. Evans and B.J. McCormick

INTRODUCTION

Ontario Hydro is proposing to redevelop an existing four-station hydroelectric generation complex on the Mattagami River in northeastern Ontario north of Kapuskasing (Figure 7.1). The river flows north to the Moose River and subsequently to James Bay. The proposed extensions would add 381 MW of installed capacity to the existing facilities (450 MW). The increased capacity will meet a portion of the forecasted electrical demand of the Province of Ontario in the late 1990s. The Ontario Ministry of Energy has advocated that priority be given to the early environmental assessment of hydroelectric projects at new and existing sites. The undertaking involves an extension of one unit to each of three existing Ontario Hydro stations, and the construction of generating facilities, adjacent to the site of a fourth existing station at Smoky Falls recently purchased from Smoky Falls Power and Paper Company (SFPP).

The proposed extensions are subject to review and approval under the *Ontario Environmental Assessment Act.* An environmental assessment document was prepared and submitted to the Minister of the Environment in November 1990. This document also provides information on the project so that relevant authorities may provide the necessary clearances under the Federal Environmental Assessment and Review Process (EARP). The

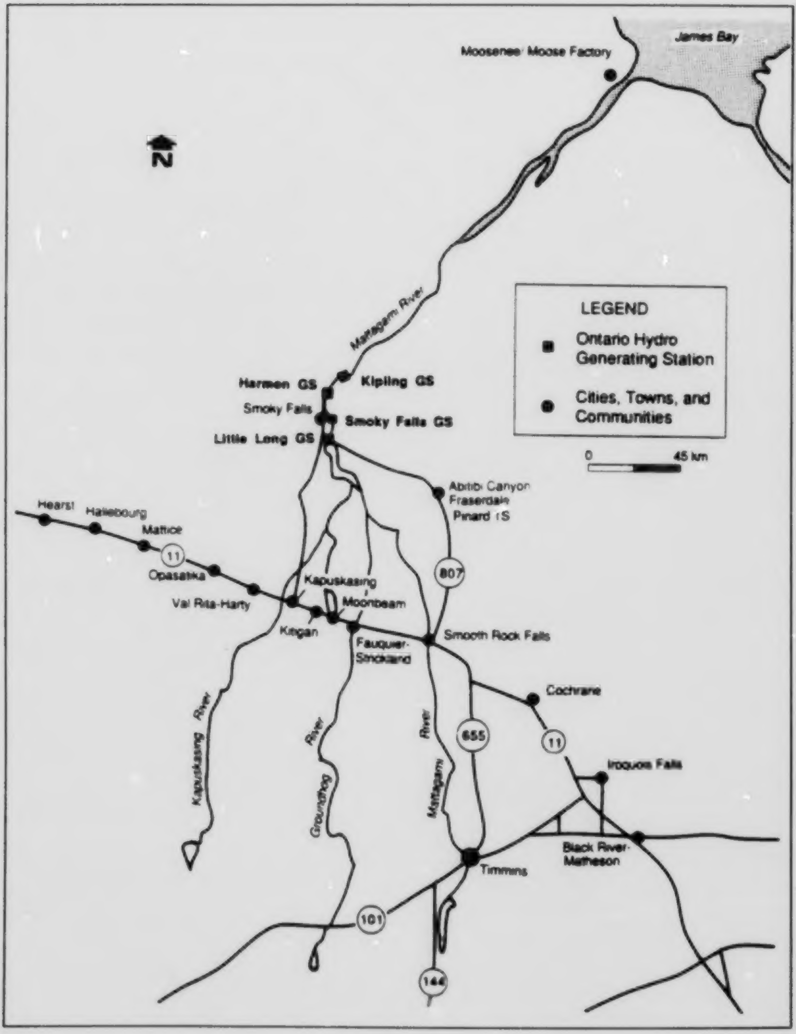
James Bay
Moosenee/ Moose Factory
N
Mattagami River
LEGEND
■ Ontario Hydro Generating Station
● Cities, Towns, and Communities
0 45 km
Harmon GS
Kipling GS
Smoky Falls
Smoky Falls GS
Little Long GS
Abitibi Canyon
Fraserdale
Pinard TS
Hearst
Hallebourg
Mattice
11
Opasatika
Val Rita-Harty
Kapuskasing
Moonbeam
Kitigan
Fauquier-Strickland
Smooth Rock Falls
807
Cochrane
11
655
Iroquois Falls
Black River-Matheson
Timmins
101
144
Kapuskasing River
Groundhog River
Mattagami River

FIGURE 7.1. Mattagami River extension location

environmental assessment is the culmination of several years of intensive study. During the assessment process, a broad range of issues were identified. Measures were identified to eliminate or minimize project effects and a framework for the long-term monitoring of effects was recommended.

This paper presents an overview of the proposed development, summarizes the key project issues, and outlines measures which were selected to reduce potential adverse effects on the natural environment.

PROJECT DESCRIPTION

The existing four station complex has been in operation for many years. The Smoky Falls station was placed in service in 1928 by the Spruce Falls Power and Paper Company. Since that time, Smoky Falls Generating Station (GS) has provided power to the company's pulp and paper mill in Kapuskasing. In the 1960s, Ontario Hydro constructed additional facilities in the vicinity of Smoky Falls. These included Little Long GS (1963), Harmon GS (1965) and Kipling GS (1966) (Figure 7.2). At that time, the Adam Creek Diversion (1963) was also constructed to bypass flows in excess of the station capacities around the four station complex.

The potential for increased generation at each was recognized during the design of the three Ontario Hydro stations. The Ontario Hydro facilities were limited by the design capacity of the Smoky Falls GS. The stations were designed with provision for future expansion, contingent upon the redevelopment of the Smoky Falls site. The installed capacity will increase by 61 MW at Little Long GS, 68 MW at each of Harmon and Kipling GS, and 184 MW at the new Smoky Falls GS. The existing 4 x 14 MW station at Smoky Falls GS will be retired (Acres, 1990). The extensions will make use of existing dams and reservoirs, and there will be no flooding associated with this undertaking.

Flows in the Mattagami River are highly regulated as a result of the operation of the existing four hydroelectric stations. The proposed redevelopment will permit in-step operation of all four stations. In-step operation will lead to a stabilization of water levels in the Smoky Falls, Harmon and Kipling headponds. The Little Long headpond will continue to be used for water storage and existing water-level fluctuations will not be altered.

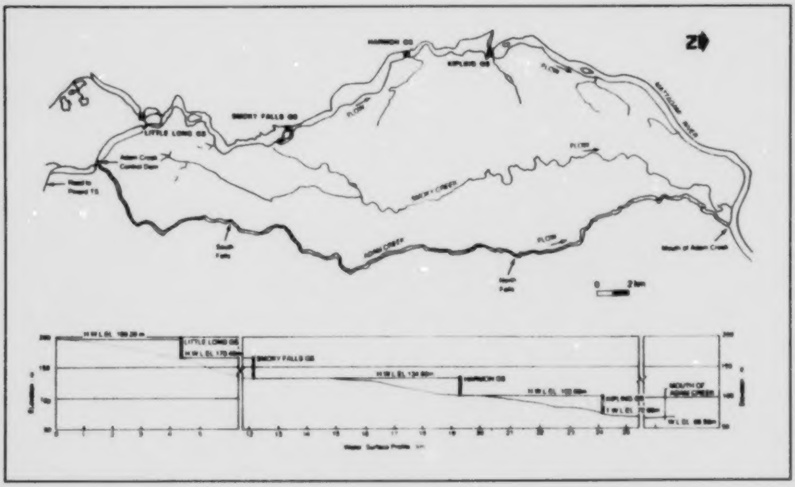
HARMON GS
KIPLING GS
SMOKY FALLS GS
LITTLE LONG GS
FLOW
MATTAGAMI RIVER
SMOKY CREEK
ADAM CREEK
Mouth of Adam Creek
0 2 km
SMOKY FALLS GS
HARMON GS
MOUTH OF ADAM CREEK

FIGURE 7.2. Mattagami complex area layout

A construction camp will be located at the project site approximately 1 km north of the Harmon GS in an existing clearing. The camp will accommodate those members of the workforce wishing to reside on site and will provide necessary health care and recreational needs. A number of the personnel, particularly married workers, may select accommodation in Kapuskasing.

PROJECT SETTING

The Mattagami River runs through the Precambrian Shield and the Hudson Bay Lowlands. Vegetation in the vicinity of the stations is typical of boreal forest. Immediately downstream of the Kipling GS, the boreal forest of the Canadian Shield changes to the Hudson Bay Lowlands where poor drainage and climate retard tree growth.

Wildlife in the area is characteristic of that found throughout the boreal forest of northeastern Ontario. Moose is the major species, but the population is relatively sparse as the Mattagami River area generally does not provide optimal habitat.

Bird, amphibian and reptile species are typical of the surrounding area; fish species in the Mattagami River are similar to those found in large northern Ontario rivers, (*e.g.*, walleye, northern pike, lake sturgeon, sucker, small forage fish). Studies have indicated that there are no rare or sensitive habitats or species that will be affected by the project.

In the area, forestry is a major resource use activity. The area's mineral resources tend to be low, although kaolin and silica deposits have been identified, and there are plans to develop a kaolin deposit adjacent to the Kipling GS.

Hunting and trapping provide a source of food and remain a traditional activity of local residents, including Aboriginal People. Hunting is also a common recreational activity in the project area.

Sport fishing in the Mattagami River and surrounding lakes is common with walleye and sturgeon being the most popular fish caught. Downstream of the Kipling GS, towards Moosonee and Moose Factory, sturgeon and other species form an important traditional harvest for the Aboriginal population.

There is an indication that humans have occupied the area from 5,000 to 2,500 years ago. In 1776, the Hudson Bay Company opened the first European establishment in the area. Evidence is still present of portage trails around the earlier rapids used by the 'brigades' for trading in the last century.

The social environment that will be most directly affected by the project will be the Kapuskasing economic development area, including Kapuskasing and neighbouring communities. This area was targeted for more detailed study; it supports a population of approximately 17,000 people, and includes the communities of Kapuskasing, Smooth Rock Falls, Val Rita-Harty, Moonbeam, Fauquier-Strickland, Opasatika, Fraserdale and Smoky Falls (Figure 7.1). The communities in the area are resource-based, with a heavy reliance on the pulp and paper industry. Due to widespread reductions in forestry and logging operations, and in other local industries, unemployment has tended to be higher than the provincial average.

ENVIRONMENTAL ISSUES AND EFFECTS

The environmental assessment process for the project was officially started in 1989, and undertaken over a period of several years by Ontario Hydro staff with the assistance of a number of consulting firms. Potential project effects were identified through extensive baseline studies, scientific investigations and consultation with technical experts, Aboriginal People, government representatives (provincial and federal), elected officials, and members of the public. Public and government involvement programs were conducted to ensure issues were fully identified and considered in the assessment. Through workshops, information centres, meetings, newsletters, and release of draft EA Scope document, efforts were made to provide information on potential project effects, to obtain a clear understanding of concerns, and to the extent possible, to resolve those concerns (Ognibene, 1990).

As part of the EARP process for this undertaking, close liaison was maintained with various federal government agencies. For instance, federal and provincial agencies participated at an EA Effects Workshop held in June 1990. Numerous meetings were held with the Department of Fisheries and Oceans (DFO), the lead agency under EARP, to resolve project concerns, particularly relating to potential fisheries effects.

Although conceptual studies and collection of baseline environmental information commenced in the early 1980s, the EA process was not formally initiated till the fall of 1989. It was at this time that the negotiations between Ontario Hydro and SFPP for the sale of Smoky Falls GS were successfully completed.

Through the EA process potential construction and operation sources of effect on the natural environment were identified. Valued Ecosystem Components were determined (Table 7.1).

TABLE 7.1
Valued Ecosystem Components
Natural Environment

Fish Population	
- upstream of Little Long GS	- sturgeon - walleye
- downstream of Kipling GS	- sturgeon - walleye
- Adam Creek	- sturgeon
Fish Spawning Habitat	- downstream of Kipling GS - headponds
Sport Fisheries	- upstream of Little Long GS - downstream of Kipling GS - headponds
Hunting, Trapping and Subsistence	- Little Long GS, Smoky, Harmon and Kipling headponds - downstream of Kipling GS
Recreational Use	- downstream of Kipling GS
Heritage Resources	- Smoky Falls GS

Environmental Assessment Issues

Some of the key natural environment issues are as follows:

(1) Operation of the generating station extensions will or may result in:

- Increased daily fluctuations in downstream flow rate and water levels (*i.e.*, below Kipling GS)

- Dewatering of habitat during weekend shutdowns
- Increased erosion of river banks below Kipling GS
- Disruption of downstream walleye and sturgeon spawning (*i.e.*, below Kipling GS)
- Increased entrainment of fish (adult and larval) through the Complex
- Disruption of waterfowl enhancement program in Little Long headpond
- Stabilization of water levels in the Smoky Falls, Harmon and Kipling headponds
- Reduced quantity and duration of spillage to the Adam Creek Diversion
- Disruption of downstream river navigation (*i.e.*, below Kipling GS) by resource users

(2) Access road improvements and the presence of the workforce will or may result in:

- Increased hunting and fishing pressure
- Increased road kills
- Increased competition for resources (*e.g.*, aggregate)
- Disturbance of nesting bird colonies
- Degradation of fish habitat at stream crossings

(3) Site preparation will or may result in:

- Clearing of forest vegetation
- Loss of wildlife habitat
- Effects on traplines/trappers

(4) Cofferdam placement and removal will or may result in:

- Localized effects on water quality
- Downstream sediment deposition
- Disturbance of fish habitat

(5) Construction of the generating station extensions will or may result in:

- Reduction in aquatic habitat from dewatering
- Loss of heritage resources

The issues listed above reflect the primary concerns of the government agencies, the public, Aboriginal People, and special interest groups. The priority given to an issue varied with the interests, mandate or goals of the particular organizations. Most concern was expressed regarding the following issues: (1) aquatic effects downstream of Kipling GS, (2) the effects of the Adam Creek Diversion, (3) erosion in the Smoky Falls, Harmon and Kipling headponds, (4) the relationship of the project to the Moose River Basin Plan and the Demand Supply Plan, (5) potential interference with a waterfowl habitat enhancement program upstream of the proposed extension, and (6) the need for a detailed pre- and post-construction monitoring program.

Reluctance on the part of the Aboriginal People to become fully involved in the Mattagami EA process, and the tabulation and resolution of their concerns were also issues during the EA. An offer by Ontario Hydro to participate in the EA process, including funding of resource use studies, was declined by the Moose River James Bay Coalition because of broader concerns with the Demand Supply Plan and the Moose River Basin Plan.

Some of the significant issues associated with the proposal are discussed briefly.

The increased capacity of the four plants along the Mattagami River will necessitate less spilling down Adam Creek during high flow periods. Geotechnical studies on erosion within Adam Creek predicted that with the reduction in the maximum spill as well as the duration of spill down the creek, the project will not aggravate existing erosion (Huang, 1987). Therefore, erosion and downstream deposition is not an EA issue but is an operational matter. Outside the EA, Hydro initiated a study in 1990 of the erosion which has occurred in Adam Creek including downstream deposition.

Members of the public have reported the stranding of sturgeon in Adam Creek and questioned what would happen with the proposed extensions. The new operating regime with the extensions will result in a spill of reduced total duration that will also tend to end sooner in the year. Radio-tracking studies with sturgeon (McKinley, 1990) indicate that the majority of tagged fish were further upstream during the period of the year when the Adam Creek Control Structure would be closed under the new operating regime. Therefore, it is predicted that fewer fish will be entrained in the Adam Creek pools below the control structure. Nevertheless, although entrapment is not a consequence of this undertaking, Ontario Hydro is committed to monitor annual entrainment into Adam Creek and review long-term solutions to address the concern (Evans *et al.,* 1992). Potential aquatic effects downstream of Kipling GS were assessed (Carson *et al.,* 1990) including mitigation options to prevent dewatering.

Construction of the generating station extensions will or may result in reduction in aquatic habitat from dewatering, and a loss of heritage resources.

Increased erosion within the Smoky, Harmon and Kipling GS headponds was a concern expressed by several government agencies. Flows will increase through the four stations on the Mattagami River with the proposed extensions. However, with the acquisition of the base-load Smoky Falls GS and its conversion to a peaking mode, the existing daily water level fluctuations within the three smaller headponds will be reduced from up to 3 m to less than 0.5 m.

Aboriginal involvement in the process did include attendance at information centres held in Moosonee, Moose Factory and Kapuskasing. In addition, written comments on the draft Mattagami EA Scope Document were received from the Moose Factory and New Post First Nations and incorporated into the EA.

The Mattagami EA Summary Document was translated into Cree and distributed to numerous Aboriginal representatives. This effort, a first for Ontario Hydro, has been well received.

MEASURES TO MINIMIZE ENVIRONMENTAL EFFECTS

Following analysis of environmental data and a review of concerns expressed by relevant stakeholders, Ontario Hydro developed various measures to eliminate or minimize potential adverse effects and enhance beneficial effects. The development of mitigation measures for potential environmental effects is covered by corporate policy which establishes priority as follows:

(1) eliminate where reasonably achievable;

(2) reduce to the lowest reasonably achievable;

(3) regulate to an acceptable level or to an acceptable time period; and

(4) create another benefit to partially or fully off-set the effect.

Basic EA issues centre around operation of the extensions, operation of the Adam Creek Control Structure and project construction. The following net effects were predicted through the EA process.

(1) Operation of the generating station extensions

- Flow rates and water level fluctuations will increase downstream of Kipling GS with the addition of the third unit
- Minimum water levels will be maintained and no additional dewatering will occur
- Velocities downstream of Kipling GS will increase by as much as 20 percent (0.4 m/s)
- No increase in erosion downstream of Kipling GS will occur
- No disruption in downstream spawning predicted (habitat enhancement proposed)
- No significant increases in fish entrainment is expected
- Stabilization of water levels in the Smoky Falls, Harmon and Kipling headponds is expected. This will reduce the potential for erosion and improve aquatic habitat

- Reduced spillage to the Adam Creek Diversion is expected which will reduce erosion and the potential for passage of sturgeon into Diversion
- No change to downstream navigation is predicted

(2) Access road improvements and the presence of the workforce

- Improved access will result in increased additional angling and hunting pressure on fish and wildlife populations and may create competition with current resource users including Aboriginal People who may use the project area to meet their needs
- Increased usage of the access roads will result in marginal increase in road kills
- Potential disturbance of nesting bird colonies will be minimal
- No effects are predicted due to suspended material deposition or creation of barriers to upstream movement at stream crossings

(3) Site preparation

- The loss of 6 ha forest vegetation at Smoky Falls will have a minimal effect on regional species populations and resource use
- Short-term disruption in trapping patterns may occur but no decline in harvest is predicted, no trapping currently takes place on the Smoky Falls Island

(4) Cofferdam placement and removal

- Cofferdam placement and removal will result in some minor short-term increases in turbidity in the tailrace of each station. Water quality changes will be minimal and are not predicted to affect aquatic life

(5) Construction of the generating station extensions

- Construction activities will take place behind cofferdams and rock plugs. Hence the effects on fish population will be minimal
- Only short-term and localized dewatering effects will occur during construction
- Blasting in the river will be minimal and hence blasting shock is not expected to affect fish populations
- No heritage resources will be lost near the proposed extensions and construction camp

The appropriate mitigative measures for each of the broad categories of issues are listed below.

(1) Operation of the generating station extensions:

- Water levels will be maintained below Kipling GS to minimize the potential for desiccation of sturgeon eggs following spawning
- Existing minimum water levels will be maintained below Kipling GS to ensure that there will be no net loss of aquatic habitat
- Existing minimum water levels will also minimize further aggravation of river travel downstream of Kipling GS
- Suitable spawning habitat will be created in the tailrace of the new Smoky Falls GS

(2) Access road improvements and the presence of the workforce:

- A closed or limited fishing season for the duration of the construction period is recommended for consideration by MNR Ontario Hydro will monitor effects on fish populations and angling effort and co-operate with MNR to ensure recovery of fish population. Gun control will be enforced within the construction site boundaries.

- The use of boats, all-terrain vehicles and snowmobiles will be minimized in the construction area and private boats etc. will not be permitted on the camp-site. Construction vehicles will be restricted to designated trails
- Construction staff will be instructed on the sensitivity of fish and wildlife population to their activities
- Ontario Hydro will recommend that speed limit signs be erected and good driving practices encouraged
- Use of local aggregate resources will be maximized to minimize competition with other pit users
- Noise control practices will be implemented and construction staff will be educated to the sensitivity of wildlife to noise and harassment

(3) Site Preparation:

- Ontario Hydro will compensate trappers for any financial losses resulting from the project. Trappers will also be provided with assistance in entering areas which will otherwise have restricted access.
- Areas cleared during construction, including aggregate pits and grounds surrounding the generation facilities, will be landscaped and/or revegetated

(4) Cofferdam placement and removal:

- Cofferdams will be non-erodible cellular types or will be protected with erosion resistant material. Sheet piling may also be used to reduce erosion.
- The timing of cofferdam construction will consider lake sturgeon and walleye spawning periods

(5) Construction of the generating station extensions:

- The timing of dewatering at each station site will consider sturgeon and walleye spawning periods

- Ontario Hydro will train staff on how to deal with any accidental archaeological 'finds'
- Smoky Falls GS, including the existing dam, will not be removed to make room for the new powerhouse and thus it will not be lost in the context of a potential heritage resource

As with other developments of this kind, the Mattagami Extensions will have some residual adverse effects. In these instances, mitigation measures are proposed to reduce the adverse effects to minimal levels or limit effects within acceptable time periods. For instance, in response to additional angling and hunting pressure by the work-force, measures are proposed to restrict and discourage excessive hunting and angling activities. If adverse impacts are experienced by the local bear hunting outfitter, Ontario Hydro will minimize any impacts. A small portion of terrestrial and aquatic habitat will be permanently altered. This loss will have a minimal effect on regional species populations and resource use. New spawning habitat will be created in the tailrace of the new station. Ontario Hydro will co-operate closely with the Kapuskasing Economic Development Committee and Chamber of Commerce to ensure businesses are aware of project schedules and to minimize over expanding in anticipation of growth.

PROPOSED MONITORING PROGRAM

Following approval of the undertaking, Ontario Hydro has proposed to undertake a multi-phase, pre- and post-operational program designed to monitor the effects on the environment from the project. Objectives of the program are to:

(1) identify significant changes to the environment resulting from the project;

(2) verify predictions and prediction methodologies;

(3) assess effectiveness of mitigation measures;

(4) demonstrate compliance with EA commitments and conditions of approval; and

(5) identify the need for additional mitigative or remedial actions.

The monitoring program will begin prior to construction and continue on into the operating component of the project.

Initial components of a monitoring program are outlined in Table 7.2 and a scoping process to develop the details of the monitoring program is proposed in the EA. A workshop process, including the participation of regulatory agencies, Aboriginal representatives and other stakeholders has been proposed to define the specific details of the monitoring program.

TABLE 7.2
Proposed Monitoring Program

- evaluation of post-development fish populations in the Little Long, Smoky Falls, Harmon and Kipling Reservoirs
- evaluation of the effects of sturgeon and walleye spawning in the Mattagami River, below Kipling GS
- evaluation of the effects on walleye and sturgeon of reduced flow diversion to Adam Creek
- evaluation of effects on resource users, including trappers and Aboriginal Peoples
- confirmation of reservoir dissolved oxygen, temperature and nutrient predictions

Study components which are developed will be reviewed with affected public interest groups. On an annual basis, reports will be prepared and circulated for review by regulatory authorities and affected groups.

CONCLUDING REMARKS

Ontario Hydro has concluded that the Mattagami River hydroelectric development is one of the preferred new supply alternatives to meet the electrical energy demand of Ontario. The EA completes a multi-year assessment of project alternatives, public and government concerns, environmental effects, and impact mitigation and monitoring requirements. Numerous opportunities have been provided for input by government reviewers in the scoping of field study programs, identification of a broad range of issues, prediction of impacts, selection of mitigation techniques, and the content of the EA submission.

Efforts have been made to inform those affected about the proposed development and to obtain feedback on their concerns. This feedback has and will continue to influence the decisions relating to the implementation of this development. With the proposed mitigation measures, the effects of proposed extensions on the natural environment will be localized and temporary. All identified effects are both predictable and manageable.

The Mattagami Extensions makes more efficient use of the water resources provided by the Mattagami River and this undertaking offers:

- a renewable, indigenous source of electrical energy;
- one of the best capacity and energy characteristics surpassing most other concept phase hydroelectric options;
- no new sources of environmental contamination including insignificant atmospheric emissions, liquid effluent and solid wastes;
- no flooding of land and associated release of mercury or other heavy metals;
- insignificant effects on fish and wildlife;
- minimal effects on vegetation and wildlife habitat;
- very limited changes to the physical landscape;
- minimal effect on resource users including Aboriginal Peoples;
- up to 2,035 person years of direct project employment;

- approximately 250 jobs through indirect employment of which 80 percent will be filled by local residents; and

- substantial spending which may be experienced by Kapuskasing businesses.

The Mattagami EA was submitted for review and approval to the Ontario Ministry of the Environment in November 1990. It continues to be under review by provincial and federal governments.

Ontario Hydro was unable to achieve the desired level of participation by Aboriginal People in the EA process. This issue remains a matter of some concern to the Corporation. The Corporation has made a commitment to work co-operatively with Aboriginal People to resolve their concerns. An offer to plan the development in partnership with affected First Nations remains outstanding.

Ontario Hydro is fully committed to the monitoring of project impacts and development of appropriate mitigation to reduce impacts or provide offsetting benefits. Programs to monitor impacts on both the local community and the natural environment have been proposed.

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CHAPTER 8

THE APPLICATION OF THE CANADIAN ENVIRONMENTAL ASSESSMENT PROCESS TO DAMS: A CASE STUDY OF THE RAFFERTY-ALAMEDA PROJECT

W.J. Stolte and M.H. Sadar

INTRODUCTION

The Rafferty-Alameda project in southeastern Saskatchewan generated controversy pertaining to the environmental impacts associated with it from the time this project was proposed in 1986. The reasons for this lie not so much in the environmental impacts of the project as in its timing. Recently, there have been rapid changes in public and judicial perceptions regarding the importance and relevance of federal and provincial environmental assessment processes. This paper deals with the application of the Federal Environmental Assessment and Review Process (EARP) to the Rafferty-Alameda project.

The paper describes the geography of the Souris River basin, and outlines the history and objectives of the project. The provincial and federal EIA processes are reviewed, and the purpose and procedures of the EARP Panel are discussed. The issues relevant to the Rafferty-Alameda project are addressed, particularly with respect to downstream impacts. The recommendations of the panel, as made public in September 1991, (FEARO,

1991) are outlined. The discussion also evaluates the effectiveness and relevance of EARP to the Rafferty-Alameda project.

THE BASIN, THE PROJECT, AND PROJECT OBJECTIVES

The report by the panel (FEARO, 1991), released in September 1991, gives a succinct description of the basin, the project, and its objectives.

Watershed Description

The Souris River is a tributary of the Nelson River system draining into Hudson Bay (Figure 8.1). Originating in undulating prairie lands southeast of Regina, it flows past Estevan and into North Dakota. It loops back to the northeast near the city of Minot and crosses the North Dakota/Manitoba border near Westhope. It then meanders north across southwestern Manitoba until it joins the Assiniboine River southeast of Brandon. About one-third of its 62,120 km^2 drainage basin above this junction lies within Saskatchewan. Long Creek and Moose Mountain Creek are the principal tributaries in the Saskatchewan portion of the Souris watershed. These creeks and the main stem of the Souris River meander through flat valleys incised into the gently rolling prairie landscape of the basin. Des Lacs, Wintering and Deep Rivers are important North Dakota tributaries. In Manitoba, major tributaries are Plum Creek, Gainsborough Creek and Antler River.

A semi-arid continental climate prevails throughout much of the watershed. Drought, occasional thunderstorms and intense temperature variations are typical of the climate. Snowmelt in the spring can generate over 80 percent of the annual streamflow and causes most of the flooding. At times, periodic droughts eliminate streamflows altogether.

The Souris basin ecology reflects the semi-arid prairie climate and topography. The natural upland vegetation of the Souris basin is a mixed grass prairie, although some species that are characteristic of tall grass prairie vegetation are found in certain locations. There are trembling aspen

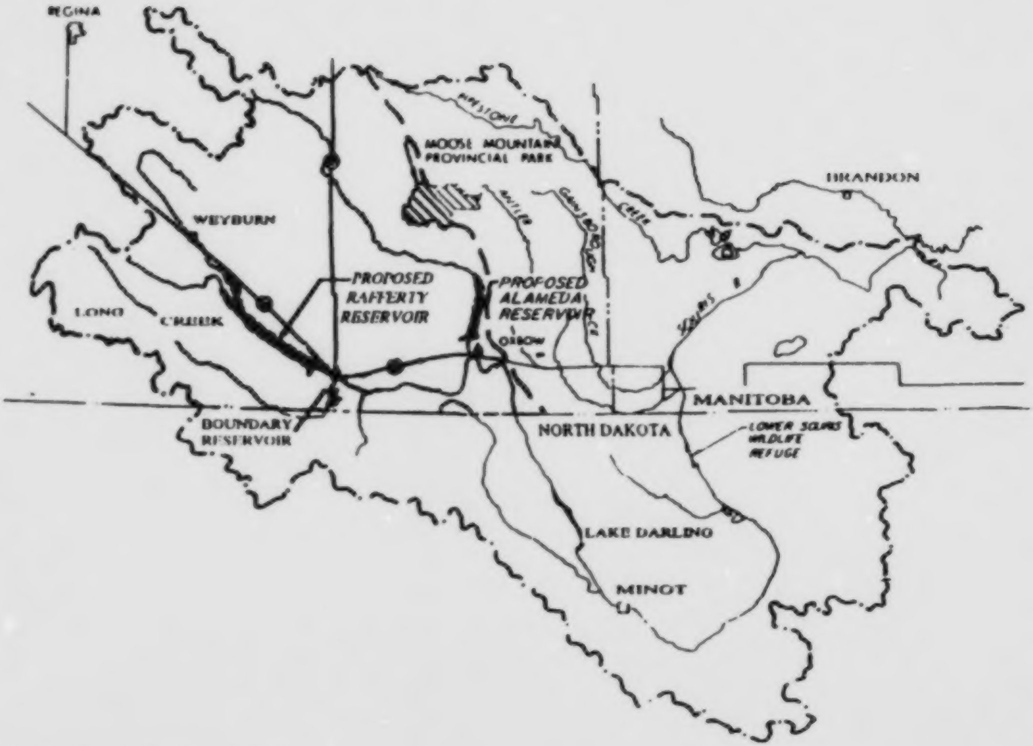
REGINA
WEYBURN
LONG CREEK
BOUNDARY RESERVOIR
PROPOSED RAFFERTY RESERVOIR
MOOSE MOUNTAIN PROVINCIAL PARK
PIPESTONE
ANTLER
GAINSBOROUGH CR
CREEK
PROPOSED ALAMEDA RESERVOIR
OXBOW
BRANDON
SOURIS R
MANITOBA
NORTH DAKOTA
LOWER SOURIS WILDLIFE REFUGE
LAKE DARLING
MINOT

FIGURE 8.1. Souris River basin

groves in depressional uplands, especially in the eastern portion of the area. Manitoba maple, green ash, and various shrubs grow on river levees and in sheltered locations at the edge of the floodplain. Wetlands are found along the shores of rivers, creeks, small lakes and reservoirs in the basin. Most of the uplands and parts of the valleys are now under intensive cultivation, while much of the remainder is used as hayland or pasture.

Segments of the local population and some provincial agencies have been promoting water-based development to diversify the local economy, and to strengthen the economic base of rural communities. Since the turn of the century, coal has been a major contributor to the local economy. Oil production since the 1950 has added further to the industrial base.

There are eight smaller reservoirs in the Souris River basin upstream of the North Dakota border which provide municipal, agricultural and industrial water supplies, as well as some recreation. The total combined storage of these structures and about 4,900 farm dugouts is 116,100 dam^3. This total represents about one-fifth of the combined storage of the Rafferty and Alameda reservoirs. The largest existing reservoir, created by Boundary Dam on Long Creek, is southwest of the Rafferty Reservoir. It supplies cooling water for thermal power generation and municipal water to the City of Estevan. The next largest reservoir in the study area, Nickle Lake, is downstream of Weyburn and supplies water to that city.

Important developments in the North Dakota portion of the basin include the Upper Souris (Lake Darling) and J. Clark Salyer National Wildlife Refuges. Lake Darling is a valued local fishery and both refuges provide important habitat for a variety of migratory waterfowl. The City of Minot, south of the refuges, is built on a floodplain and has been subject to severe flooding in the past. In Manitoba, the Souris is a source of municipal water and is used for recreation, including fishing.

Project Description

The main components of the project are the Rafferty Dam on the Souris River and the Alameda Dam on Moose Mountain Creek. Other, smaller components are also included and described below. The project, once completed, will be managed by the Saskatchewan Water Corporation (SaskWater).

Rafferty Dam is the larger of the two dams. It is a 20 metre high earth-fill dam located 6 km northwest of Estevan. When full, the Rafferty Reservoir will stretch 57 kilometres upstream, have a surface area of 4,900 hectares and store 440,000 dam^3 of water. Weirs in three areas upstream of the main dam will control water levels for waterfowl and fish production.

The Alameda Dam will be a 38 metre high earth-fill dam on Moose Mountain Creek north of the Town of Oxbow, relatively near the North Dakota border. It will eventually create a 105,000 dam^3, 1,240 hectare reservoir extending 25 km upstream from the dam. This reservoir, though smaller than Rafferty Reservoir, will be considerably deeper. Consideration is being given to using weirs to promote development of waterfowl habitat at four upstream locations.

There are a number of other projects associated with the development of the two dams (Figure 8.2). There is a diversion channel connecting the Rafferty Reservoir to the nearby Boundary Reservoir. This channel allows for the movement of water in either direction and joint operation of the two reservoirs. In addition, a pipeline from the Rafferty Reservoir will supply cooling water to two turbines at the new Shand power station 10 km southeast of Estevan. Channelization of 16 km of the meandering river course below Rafferty Dam is intended to alleviate local flooding problems and to reduce losses of water to seepage and evaporation.

Since the present Dr. Mainprize Regional Park located south of Midale will be inundated by reservoir waters, the park will be relocated to an area further upstream on the Dead Lake channel. Weirs will be used to prevent flooding of the new site by reservoir waters. A weir upstream of the Rafferty Dam will supply municipal water to Midale.

An important feature of the overall project is its operating complexity. The two new reservoirs are to be operated in concert with the existing Boundary Reservoir to meet a number of objectives. The scheme involves inter-reservoir water transfers, a multi-reservoir operating regime, two national, one state and two provincial governments, and their respective agencies.

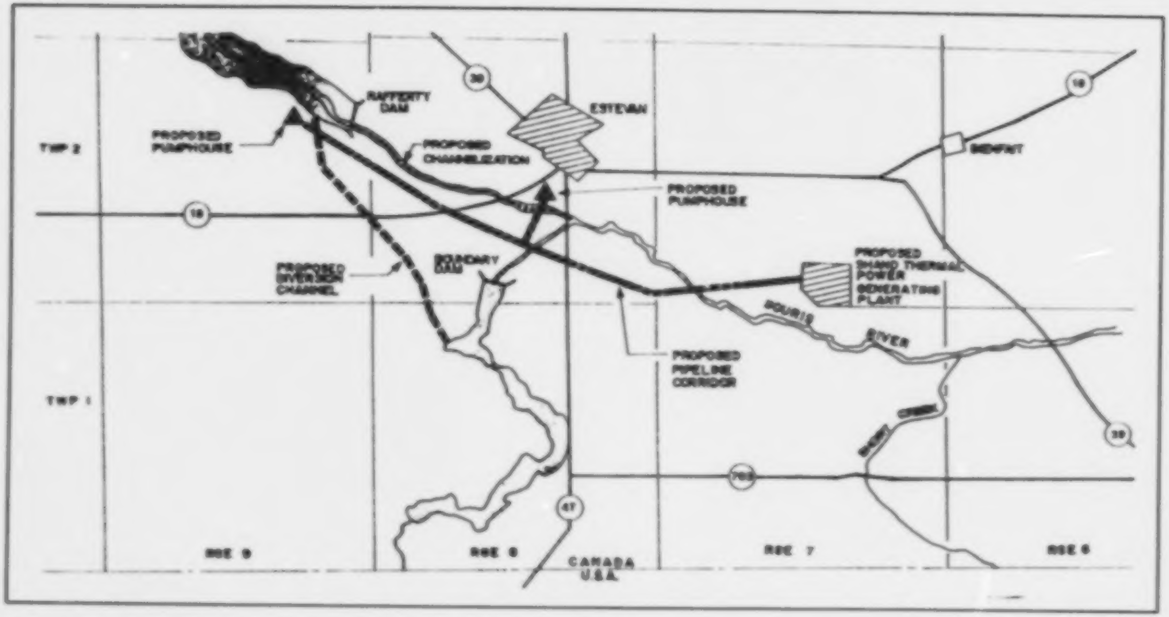
RAFFERTY DAM
ESTEVAN
PROPOSED PUMPHOUSE
PROPOSED CHANNELIZATION
PROPOSED PUMPHOUSE
BIENFAIT
PROPOSED SHAND THERMAL POWER GENERATING PLANT
BOURIS RIVER
PROPOSED DIVERSION CHANNEL
BOUNDARY DAM
PROPOSED PIPELINE CORRIDOR
CREEK
TWP 2
TWP 1
RGE 9
RGE 8
RGE 7
RGE 6
CANADA
U.S.A.
39
18
18
39
47
705

FIGURE 8.2. New facilities associated with Rafferty Reservoir

Project Objectives

The objectives of the project were specifically detailed in the panel report (FEARO, 1991). Briefly, these objectives include the following:

- comply with the terms of the 1989 Agreement between Canada and the United States of America for water supply and flood control in the Souris River basin. This agreement covers water management criteria and reservoir operating criteria for apportionment and flood control including flood protection at Minot, North Dakota, for the 100-year flood.

- provide an assured long-term water supply to the Shand power station. It is a new coal-fired generating station located near Estevan which incorporates much of the latest technology in its design. Its requirement for cooling water will be partially fulfilled by treated effluent from the Town of Estevan, and pumping from Rafferty Reservoir. Shortfalls in these supplies will be met by pumping from groundwater.

- provide an adequate water supply for existing authorized water users in Saskatchewan, including municipal, irrigation, domestic and industrial water users.

- provide an adequate water supply for new developments in the Souris River basin which could include up to 4,800 hectares of new irrigation development.

- operate the Rafferty Reservoir and the Alameda Reservoir to provide recreational benefits.

- provide flood protection to urban and rural areas downstream of the Rafferty and Alameda Dams.

- operate a flow regime in the Souris River and Moose Mountain Creek which will maintain acceptable water quality, and when possible, enhance fish habitat and aquatic wildlife habitat. Instream flows should be supplied by water designated to meet Saskatchewan's apportionment obligations as dictated by the *Boundary Waters Treaty* (1909) and the *Interim Measures Agreement* (1959).

- provide an adequate water supply for wildlife enhancement measures. This will include approximately 1,000 hectares of wetlands development within and alongside the Rafferty and Alameda Reservoirs.

How these objectives are met when reservoir operating regimes are developed will, in part, reflect the legal obligations that are binding on the water management authority of the system. The 1989 Agreement between Canada and the United States sets out terms related to water apportionment and water quality at the international border. The U.S. water entitlement is defined by a set of rules based on the amount of storage in Lake Darling in North Dakota, and the natural streamflow at the border. The rules stipulate the percentage of the natural flow at the international border which is to be passed to North Dakota, allocating 50 percent of the natural streamflow to North Dakota in dry years and 40 percent in other years.

In addition to the operating objectives listed above and under the terms of the 1989 Agreement, the Souris River Basin International Water Quality Objectives were developed by the Water Quality Objectives Task Force of the Souris River Bilateral Water Quality Monitoring Group. These objectives cover 46 parameters grouped into four categories: biological (1 parameter), inorganic compounds (22 parameters), organic compounds (17 parameters), and miscellaneous (6 parameters). For each parameter, the 1989 Agreement identifies the most sensitive use being protected and the possible source of the contaminant. The objectives apply to Souris River waters as they cross both the Saskatchewan/North Dakota border and the North Dakota/Manitoba border.

The water quality objectives are intended to protect and provide sufficient water quality in the Souris River so that instream uses, such as domestic consumption, fish and wildlife resources, irrigation, livestock watering, and industrial consumption are maintained. The numerical values for the water quality objectives for the Souris River at the two boundary sites were arrived at through a process that considered the objectives, guidelines and/or standards of the participating agencies, the historical water quality, and the monitoring capabilities of the various agencies.

HISTORICAL BACKGROUND OF THE PUBLIC CONTROVERSY ASSOCIATED WITH THE PROJECT

In the recent past, there have been rapid and dramatic changes in the way society views the physical environment. The public is well aware that a number of development projects that have been completed in Canada in the past 20 years have caused considerable environmental damage. The Bennett Dam in British Columbia and its impact on the Peace-Athabasca Delta is one example. Furthermore, society of necessity is rapidly becoming sensitized to the global environmental damage associated with acid rain, the depletion of the ozone layer, and other forms of pollution.

The Rafferty-Alameda project was proposed and developed during a time of growing public awareness and concern about the natural environment. The idea of water management on the Souris River has been discussed for the past many decades. Studies on the system were originated in 1940, 1957, and in the 1970s. The present project is a climax to all these previous efforts. However, the expectations of the Canadian public regarding the environmental acceptability of such projects has changed dramatically from what they were in March 1986, when the Souris Basin Development Authority (SBDA) was created by the Saskatchewan Government as a Crown Corporation.

The SBDA was given the authority and responsibility of designing and building the components of the project, with the help of other governmental agencies such as Saskatchewan Water Corporation (SaskWater) and Saskatchewan Environment and Public Safety (SEPS). The SBDA was required to meet all the conditions of the Saskatchewan environmental assessment process. This process includes the following steps:

(1) Proposal is submitted.

(2) Saskatchewan Environment and Public Safety decides as to whether an environmental impact assessment (EIA) is required.

(3) Once the decision is made, then the project specific EIA guidelines are prepared, public notice is given, and the proponent is asked to complete and submit the Environmental Impact Statement (EIS).

(4) Public input is sought, including that from a Board of Inquiry if necessary.

(5) Approval is either withheld or granted subject to conditions.

The SBDA complied with the conditions of the Saskatchewan process in full, including hearings by a Board of Inquiry in 1987 and submitted a full report (SBDA, 1987). Since the Souris is an international river, water management concerns in the basin are subject to the *Boundary Waters Treaty* of 1909 between Canada and the United States. Accordingly, the water supply and flood control measures associated with the project required a license from the Canadian government under the *International Rivers Improvement Act* (IRIA). Environment Canada, the department having the authority to grant such a license, could have required an assessment under the EARP but chose not to do so. Environment Canada officials thought that the previously completed provincial assessment had met the EARP requirements. Therefore, following an internal assessment of the project by Environment Canada, and after consultation with government officials from Saskatchewan, Manitoba and United States, the Minister of the Environment issued the IRIA conditional licence in June 1988.

It should be noted that in 1987 the federal process (EARP) was based on the Federal Environmental Assessment and Review Guidelines Order. It was assumed that such a guidelines order was merely a Cabinet Policy Statement and not law of general applicability. This assumption seems very reasonable as the document was never tabled, discussed nor voted on by the Parliament of Canada. Hence, the federal Minister of the Environment thought that it was within his authority to waive the requirements under the Guidelines Order.

In January 1989, the Canadian Wildlife Federation (CWF) and two affected landowners filed an application with the Federal Court to set aside the IRIA licence. They contended that EARP had not been applied properly in the decision to issue the licence. The federal government argued that the requirements of EARP had been fulfilled in the assessment which had been conducted by the Province of Saskatchewan in 1987. In addition, the federal government argued that before issuing the IRIA licence, it had carried out its own review of the project.

After considering these arguments, the Federal Court concluded that the provincial review inadequately addressed areas of federal responsibility, especially potential impacts outside of the Province of Saskatchewan. These impacts, the Court decided, must be addressed, and, in April 1989, it quashed the licence and ordered the federal Minister of the Environment to conduct a review of the project under the EARP.

As required by the court, a review of the project was undertaken in the summer of 1989. Under EARP, the federal department responsible for funding or having the authority to give approval (license) for the project (in this case, Environment Canada) becomes the initiating department and is charged with conducting an Initial Environmental Evaluation (IEE). On the basis of the IEE, the Minister in charge of the initiating department, in this case Environment Canada, then makes a decision as to whether an Environmental Assessment Review Panel is required. If so, one is established and the panel reviews all the literature involved in the case, including the EIS and the IEE. It has the option of requesting more information from the proponent through first a draft set of questions and then a final set of questions. After the panel has received the answers to its questions, it holds public hearings in the relevant jurisdictions and then writes its report, submitting it to the federal Minister of Environment and the Minister responsible for the initiating department. In this case, the federal Minister of Environment wore both pairs of shoes. The initiating department is then free to undertake whatever action it considers suitable with respect to the proposal.

In the role of initiating department for the federal environmental review, Environment Canada prepared an Initial Environmental Evaluation (IEE) which addressed possible environmental impacts of the Project in areas of federal responsibility. Public meetings were held concerning the IEE in Manitoba, Saskatchewan and North Dakota between June 22 and 29, 1989. Based on recommendations contained in the IEE and input from the public meetings, the federal Minister of the Environment issued a new IRIA licence in August 1989, with more stringent conditions.

In addition to these activities under EARP, negotiations were also in progress between Canadian and American officials to arrive at a joint understanding regarding water management issues affecting both jurisdictions. By October 26, 1989, these negotiations culminated in the signing of an Agreement between the Governments of Canada and the United States, setting out terms related to both water apportionment and water quality at the international border.

At this point, in the view of the federal government, all of the necessary steps had been taken to enable the project to proceed. The second phase of the EARP, a public review by an independent environmental assessment panel, was not considered necessary by the federal Minister of the Environment. However, a second court action was initiated in October 1989 by CWF and two affected residents which resulted in a Federal Court decision requiring an independent panel review. A five-member environmental assessment panel was appointed by the Minister of the Environment on January 29, 1990 to review the environmental and related social impacts of the Rafferty-Alameda proposal.

A panel review requires a wide range of expertise since the review of almost any project will generate issues in many different scientific areas, including but not limited to horticulture, zoology, ecology, law, economy, sociology and various fields of engineering. Understandably, FEARO attempts to form a panel which has a wide range of expertise represented among its members while at the same time keeping the panel within reasonable size for the sake of process efficiency.

An innovative feature of the process developed by FEARO is the appointment of a technical review committee which assists the panel. Areas of expertise not represented on the panel are represented on the technical review committee. Thus, it is possible for the panel, with the help of the technical review committee, to address the entire range of issues raised by the project. Furthermore, the technical review committee can seek information from the proponent or other agencies without fear of contaminating the impartial stance of the panel (Sadar and Cressman, 1991).

Areas of expertise represented on the panel and technical review committee included environmental impact assessment, social impacts, fisheries, wildlife, land use/plant ecology, resource economics, hydrology, water quality, and zoology. All of these areas were of considerable importance in the Rafferty-Alameda project. The panel's mandate was to review the environmental and directly related social impacts of the Rafferty-Alameda project, including proposed mitigation measures, and the operation and structural design of the dams.

At the time of the appointment of the panel, an agreement was signed between the Governments of Canada and Saskatchewan to suspend work on the project while the panel review was carried out. The federal government agreed to pay the province $1 million a month to compensate for delays in the project's completion. The agreement, however, allowed the continuation of construction activities on the Rafferty Dam until the safety of the structure was secured.

Considerable difficulty arose over the definition of what work was required for the safety of the project with understandably more limited views held by the federal government than by the provincial government. The panel had deep concerns about the construction work that was continuing and how it impacted on their mandate. The panel expressed discomfort to the Minister of Environment Canada on several occasions. Nevertheless, the panel continued its work until the SBDA began construction on the channelization downstream of the Rafferty Dam. This construction had considerable impact on the ecology of the Souris River flood plain in that area and the panel found that this work compromised their work so significantly that they resigned in October 1990. Immediately after their resignation, the provincial government announced that work would resume at full speed. This was quite legal since the IRIA license granted in the summer of 1989 was still in effect since it had never been quashed by the courts.

Two area farmers, the Tetzlaff brothers, again approached the courts with the complaint that the requirements of a panel review of the project were not being met, even though work was continuing. Justice Muldoon agreed and stipulated in December 1990 that a new panel had to be constituted in 30 days or the license would be quashed. The federal Minister of Environment complied, and in February 1991, announced a new panel composed of Dr. J. Archer, as Chairperson and Drs. R. Riewe and W. Stolte as members. The Technical Review Committee was strengthened with 3 more members to provide additional expertise in the key areas of water quality, wildlife, and social impact. Dr. Sadar was the Chairperson of the technical review committee.

ISSUES ADDRESSED BY THE FEDERAL PANEL

Because the Souris River crosses international and interprovincial boundaries, the recommendations of the panel are influenced strongly by that consideration. It was also natural for the panel to concern itself with broad issues such as the interrelationship between agricultural practices and the thrust behind water resource development. All of these issues are reflected in the recommendations of the panel.

Most of the issues broached by the panel centred around the fact that the proposed development would lead to a reduction of water availability in North Dakota, particularly in dry years when need for water is at a maximum. This reduction in water availability is governed by the *Boundary Waters Treaty* of 1909 which stipulates that the jurisdiction in which the water originates is entitled to one-half of this water, but not at the expense of water quality. The panel considered that the use of water during dry years for the operation of the Shand Power Plant and for irrigation might cause the flows at the international boundary to be of considerably reduced quantity and quality.

Furthermore, in addition to the reduction in the water quality at the border, reduced releases of water into North Dakota and the altered timing of the releases could mean that the quality of the water in the wildlife refuges would deteriorate with deleterious effects on both fish and waterfowl production. Both these effects would be in contradiction of the federal stance with regards to fisheries and migratory birds. Furthermore, the panel was concerned that not enough was known about the flow regime including evaporation and groundwater to determine precisely that these important environmental considerations were being met. These issues were at the heart of the panel recommendations numbered 2 through 10, 16 and 19 (FEARO, 1991).

Other recommendations (11 through 15, 17, and 18; FEARO, 1991) had to do with panel concerns about how the impact of the project would be monitored and who would be responsible for required future mitigation measures, particularly since the SBDA had a very limited mandate and lifetime.

Since the panel was appointed by the federal government, it considered that it was responsible for addressing many of the broader issues that confront Canadian society, particularly as they surfaced in the Rafferty-Alameda project. Thus, the panel felt it important to reiterate its belief that doing thorough environmental assessments at the federal level was important since many issues transcend provincial boundaries (Recommendation 20; FEARO, 1991). Insofar as the federal panel review was negatively impacted by the timing of its activities, the panel also felt it important to state that it believed that such assessments should be used as planning tools, which require that they be done very early in the history of the project (Recommendation 21; FEARO, 1991).

Since the panel was charged with the responsibility of outlining the impact of the project on all affected jurisdictions, it felt that basin-wide planning was the only rational choice if the well being of all the residents of the basin were to be maximized (Recommendation 22; FEARO, 1991). Furthermore, since impacts can be propagated downstream, the panel also recommended that the Government of Canada encourage research into the character of these cumulative downstream impacts (Recommendation 30; FEARO, 1991). Another issue raised during the panel deliberations relating to basin-wide planning was that of diversion of water from Canada to the United States. Since the IRIA license contained wording that would allow the diversion of some water to our southern neighbours, and since this contradicts the stated stance of the federal government, the panel recommended that the wording of the license be clarified (Recommendation 23; FEARO, 1991).

The panel, in its deliberations, became all too aware that the effect of agricultural development in the upper portions of the Souris River basin has had, and in the future could have, considerable impact on the downstream constituencies in North Dakota and Manitoba. It considered that some of the flooding problem in Minot and other urban areas along the upper Souris basin could be due in some part to the draining of the

Yellowgrass Marsh in the headwaters of the Souris basin many years ago. Furthermore, summer fallowing and other tillage practices could also lead to increased flood flows and reduced soil moisture. These effects would lead to a demand for flood management and for irrigation, both of which are at the heart of the Rafferty-Alameda project. For this reason, the panel recommended that the federal government look very carefully at its policies with respect to agricultural issues to see if some of these policies might lead to agricultural practices that create demand for water management projects. Overall, the panel was concerned that Canadian society become more aware of the need for a conservation mentality so that our non-renewable resources such as soil, wildlife and native prairie, not be depleted because of an ignorance of and disregard for a physical environment (Recommendations 26 - 29; FEARO, 1991). It maintained that natural resources should be cherished and nurtured.

CONCLUSIONS AND SUMMARY

Recognizing that in Canada both the federal and provincial governments have responsibilities and jurisdiction over the protection and use of natural resources, it is important that the two EIAs be done in tandem so that public responses are only required one time. One of the major problems with the Rafferty-Alameda environmental reviews was that the provincial review was done far in advance of the federal review, which was done only after a major portion of the project was complete. For the health of the environmental review process in Canada, it is imperative that the provincial and federal processes be conducted simultaneously, even though the conclusions of each might be widely divergent. There are major strides being made at the present time (November 1991) in meshing the two processes.

The issues raised by the panel in its report are of considerable importance as they relate to the protection and preservation of Canada's natural resources. The panel felt that it had the mandate to provide some guidance to Canadian society in its relationship to its environment. For that reason, all those involved with the second Panel review of the Rafferty-Alameda project are convinced that the role they were given to play was an important one, albeit that the entire process was subject to considerable detrimental influences. It is important that the people of

Canada support the environmental impact assessment process that has been developed to date. It is even more important that the public support further development of procedures which will make the federal EIA of increasing effectiveness in leading the Canadian society towards a more harmonious relationship with the physical environment it has been entrusted with.

ACKNOWLEDGEMENTS

The authors wish to thank Dr. John Archer and Dr. Rick Riewe, Chairman and member of the second panel respectively, for their contribution to this paper through their involvement in writing the original material on which this paper is based and in reviewing this paper. Thanks also go to members of the first panel and members of the technical review committee who contributed much of the original material.

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CHAPTER 9

REHABILITATION OF ENVIRONMENTS AND NATURALIZATION IN WATERSHED MANAGEMENT

J.E. Fitzgibbon

INTRODUCTION

Since the early 1980s, there has been a trend to the use of 'more natural' systems for the management of water in both urban and rural environments. This tendency is particularly true for drainage and stormwater management. In general, it has been found that traditional techniques, which often utilize concrete in urban settings, are successful at removing excess water but are ineffective in removing the waste associated with this runoff. These 'hardened systems' effectively transfer the problem of stormwater runoff and contamination to the receiving water. As a result, the impact of development spreads beyond the confines of the developed area. The hardened systems also fail to support diverse plant and animal communities and lack aesthetic appeal. The development of naturalized drainage systems has taken place in response to these shortcomings.

The form of these naturalized or 'soft' systems ranges from the planting of a diverse range of vegetation, to the construction of channels which emulate the properties of a natural water course. These techniques contribute to an increase in infiltration, a reduction in pollution loads, and the stabilization of banks. It has meant the inclusion of natural woodlands and wetlands in the urban environment for hydrologic, aesthetic, and ecological purposes.

MOTIVATIONS FOR NATURALIZATION

According to Meek (1990), there is no single correct definition of what constitutes 'natural'. Despite this lack of consensus, Baines (1990) identifies several motivations for the recreation of natural environments. The first motivation is political. This is a response to the somewhat naive notion that natural areas can be created in developed environments. These reconstructed or created environments provide natural looking areas and satisfies the public's desire for an alternative landscape to the hardened and manicured systems. These types of projects are aimed at providing for alternative activities in open spaces (*e.g.*, bird watching, feeding the ducks and geese, urban fishery). The public, through volunteer organizations, schools and public interest organizations, has been actively involved in the identification and development of sites. Presently, many of these organizations promote the restoration of drainage systems and the development of natural areas in the urban environment.

The second motivation for the use of more natural systems has been the need to reduce flood flows, protect groundwater, improve water quality, maintain fish and wildlife habitat, and enhance aesthetic qualities. Many of these ecologically-oriented objectives are supported by legislation and regulation at both the provincial and local government levels. There is also a widespread public demand for more natural forms of development in urban areas and the protection of natural areas in rural environments.

The third motivation is economic. It is believed that the conversion of intensively managed built systems to more natural biotic environments will be less costly both in terms of capital investment and maintenance. While there is no systematic information base available, the monetary costs of naturalized systems in newly developed areas are generally less than those with hardened systems. This benefit must be seen in the context of associated costs. For instance, naturalized systems require more space to accommodate river channel migration and maintain stable riparian communities. These requirements are often greater than those associated with traditional systems. At present, the long-term maintenance costs of natural systems are uncertain. These costs will depend on the degree to which a site is allowed to follow a natural succession, and the degree to which the removal of debris is undertaken.

Reliance upon the natural system has long been part of traditional water management and planning. Assimilative capacity of river systems has been a foundation for water quality improvement (Veltz, 1966). Wetlands and floodplains have been used to ameliorate flood hazards. However, the intentional development of natural systems in the built system as a proactive means of quantity and quality management is relatively new (Cairns, 1988). As such, this trend raises a number of issues for water managers, basin planners and the general public whose needs and wants are served by these systems.

IDENTIFICATION OF THE POTENTIAL FOR NATURALIZED SYSTEMS

In undertaking more natural or soft systems for water resource management, objectives need to be defined clearly so that the planning, design, implementation and operation of the system can be carried out effectively. The process of defining the objectives for a naturalized water management system depends on the particular management problem (*i.e.*, ground water recharge management, stormwater runoff management, water quality improvement). The first step is to identify the degree to which a 'natural system' can exist in the context of the basin and the level of 'non-natural' modification that has taken place. Bruns (1988) identified three conditions in which complete restoration cannot be achieved:

(1) primary ecosystems;

(2) ecosystems where development prevents the recreation of conditions essential to the plant and animal community, or where the ecosystem requires too long a time to evolve; and

(3) ecosystems where the species present exist in isolated communities and do not readily recolonize disturbed sites.

Soule and Kohm (1991) maintain that sufficient knowledge is currently available to restore disturbed land. However, it is inadequate to deal effectively with despoiled land. This conclusion suggests that natural systems can only be approximated in the restoration of despoiled sites. In order to determine the degree of naturalization which can occur, an examination of conditions in the basin is necessary. This review would include the determination of the current water balance, runoff and recharge regime, habitat integrity and stability of the basin, and the nature of the proposed development.

The rational for this examination is to determine the present state of the environment and predict future changes. This kind of assessment requires that both the structural and functional aspects of the basin be assessed. To achieve this perspective, a more holistic approach to the assessment of catchments is required. At present, no standardized approach exists for this type of evaluation. However, the development of master drainage plans in Ontario represents progress in this field.

Such an assessment is most critical in areas where urban development is expanding since any undertaking to utilize a naturalized drainage system must deal with the future changes in the basin. The data on existing as well as the prediction of future conditions should be used to identify to the kinds of environments that exist in nature with similar morphological, flow, water quality and vegetative regimes. Presently, the ecological information required to identify the appropriate natural system for altered environments is not readily available. This situation reflects the historical application of ecological studies to unaltered, rather than altered ecosystems. In addition, ecological studies typically deal with individual aspects of an area such as wetlands (Cole, 1980; Garbish, 1978), stream banks (Gore, 1985; Rosgen, 1988), and woodlots (Buckley and Knight, 1990). This approach fails to provide the required comprehensive perspective.

The comparative analysis of present and future conditions will provide a means of identifying candidate restoration programs. Given the constraints on the extent to which naturalization can occur, a second decision concerns the specific method to reconstruct or create new ecosystems.

DETERMINATION OF THE BENEFITS OF NATURALIZATION

The second step in planning and designing a naturalized drainage basin system is to examine the degree to which a 'natural' system can achieve the ecological, aesthetic, economic and social objectives. At the present time, the literature dealing with the performance of naturalized systems is inadequately developed to evaluate what can be expected of any given project. This failure, in part, reflects the relatively short period of practice. It also demonstrates that relatively few hindsight evaluations of naturalized projects have been completed (Fauer and Grutzuk, 1979). At present, the individual undertaking naturalization must use the information derived from studies of existing natural systems and assess what can be expected from a given drainage system naturalization project.

In assessing socio-economic benefits, there is a need to realistically evaluate the consequences of naturalization. Frequently-mentioned social benefits include increased recreational values. This benefit is realized only to a limited extent. The areas currently under intensive recreational use may experience a decline if they are put to a more natural condition. However, the diversity of recreational experience, particularly passive types, may be enhanced. The degree to which this shift fulfils the needs of the public must be assessed.

It has been pointed out that a number of negative social effects may be generated by naturalized systems. One of the most obvious is public safety. When reviewing a plan for a naturalized recreational pathway in a floodplain, women noted that they would not use the site because of the security problem. The development of unfenced wetlands and ponds presents a drowning hazard for small children. The presence of wildlife in the urban environment may result in increased chance of animal attack. The economic benefits of naturalized drainage systems are seen to be in reduced capital cost in the construction and maintenance of the system. In general, the data available indicate reduced capital costs. However, depending on the need for maintenance of the plant succession developed on the site and the need for rubbish removal, a naturalized site may require as much maintenance effort as a manicured site. At the present time, it is felt that there is a lower cost to the maintenance of most naturalized systems.

DESIGN OF NATURALIZED SYSTEMS

To date, the design process for naturalized drainage systems has been rooted in a site-specific rather than a basin-wide planning orientation. This perspective reflects, in part, the fact that the objective of the private sector, which has been an active participant in the implementation of natural channel design, is to support development by mitigating adverse effects. The initiatives of public interest groups have generally been broader and have extended beyond a single property. However, this approach is difficult to implement because of the fragmentation of access to the land around and along a stream system.

Much of the focus of naturalization designs has been aimed at single elements rather than at the entire ecosystem. For instance, a major focus has been the ability of the drainage system to support fish. While some species of fish are indeed an effective indicator of the health of aquatic ecosystems, the development of fish habitat may not be possible in all cases. Fish habitat, while related to riparian habitat, does not necessarily provide an effective basis for riparian and wetland design. In addition, it fails to provide a sufficient basis for the design of naturalized runoff management systems (*i.e.*, infiltration and surface runoff facilities). The design process should incorporate runoff quality and quantity considerations, and riparian as well as aquatic habitat considerations. Finally, they should integrate human adjustments to either protect and conserve the naturalized system from damage, or to provide for appropriate activities.

This process requires an inventory and assessment of the existing ecosystem, an evaluation of the existing functions of the system, and the determination of its potential for naturalization. It requires the selection of appropriate forms and functions for the naturalization, and the selection of the plant communities to be introduced to the system. Grading plans, planting plans and management plans should then be drawn up. While much of this technical work is carried out by engineers, biologists and landscape architects, it is common to have public advisory committees. The participation of the public reflects their high level of interest.

IMPLEMENTATION OF NATURALIZED SYSTEMS

At present, the implementation of naturalized systems may be undertaken by private land holders, private environmental design firms, municipal parks and recreation or public works departments, or by volunteer groups. In many cases, it is also carried out by cooperative action of all of these parties. The roles played by each participant will depend on their capacity and capability. A significant factor that makes the implementation of a naturalization project different from traditional drainage developments is the role of the public. In many cases, volunteer groups will undertake cleanup, minor grading and significant components of the planting in a naturalization project. This participation requires an additional effort by the experts to train volunteers in the relevant skill and knowledge areas. However, this process has the benefit of generating public ownership of the projects, enhancing environmental awareness, and building a source of ongoing moral and physical support for the maintenance of such projects.

The integration of biological and physical components in the design requires that implementation be particularly sensitive to the problems associated with establishing living communities. It requires detailed site preparation and may mean that the establishment of the plant community takes place over a considerable period of time. This is the case when one planting is required to develop the conditions necessary for subsequent plantings. In some instances, it may require a period of years to implement a planting program.

A second concern relates to the high level of effort required during the initial naturalization period when plant communities must overcome the shock of being transplanted. The management effort varies greatly with individual species. Plafkin (1989) noted that some aquatic communities adjust to disturbance in a matter of days or weeks while others take years.

IMPLICATIONS FOR BASIN PLANNING AND MANAGEMENT

The implications of the use of naturalized systems in drainage basin management vary depending on natural and socio-economic conditions in the basin, and the objectives to be achieved. However, there are some general implications for managers. The area of environmental management that at one time was dominated by an emphasis on physical development and engineering now includes much more biological and social orientations. Traditional approaches which have focused on site development and provided for incremental change in the system are inappropriate to meet present and future needs. In their place will be system-oriented approaches, such as comprehensive basin planning and design processes. Public involvement will evolve from a role based on the receipt of information and advisory functions, to one which represents a full partnership in the management process. This partnership will be reflected at all management levels, planning, implementation and evaluation.

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CHAPTER 10

WETLAND REHABILITATION IN ONTARIO: EXPLORING UNCERTAINTIES AND CONSTRAINTS

Thomas J. Carlisle and L. Graham Smith

INTRODUCTION

In recent years, there has been a gradually increasing awareness of the ecological, social, and economic value of wetlands (Marchand and Udo de Haes, 1991). Wetlands also have significant direct economic values from resource harvesting such as timber, peat, fish and berries, and tourism and recreation. Indirect financial benefits from wetlands include flood protection, shoreline erosion protection, and water quality improvement.

Despite these benefits, wetlands around the world are under pressure from conversion into agricultural, urban, and recreational land uses through various direct, indirect and cumulative impacts (Bedford and Preston, 1988; Keddy, 1983; Snell, 1989). For example, the conterminous United States had lost fifty-four percent of its original wetland base by the mid-1970s (Dahl, 1990). In England and Wales, 4.7 million ha of wetlands had been drained by 1939 with approximately 20,000 to 25,000 ha of wetlands converted to agricultural fields per year in the mid-1980s (Nelson, 1986). Although there is a lack of accurate estimates of the rate and extent of wetland loss from presettlement to the present, gross estimates suggest that Canada has lost seventy percent of its original wetland area since the turn of the century. In the context of southern Ontario, wetland areas have diminished by sixty-one percent since European settlement (Snell, 1987).

While policies, legislation, and acquisition programs are used to maintain the integrity of present wetlands (Carlisle, 1990; Maynard, 1989), little has been done to physically compensate for historical and ongoing losses. This point highlights the need for rehabilitative management strategies to increase the quality and quantity of wetland resources. However, while substantial research at the scientific and policy levels has been undertaken in the United States and Europe to create, restore and enhance wetlands, little work in this area has been attempted in Ontario outside of the efforts of Ducks Unlimited Canada and the *North American Waterfowl Management Plan*.

This paper provides preliminary thoughts on uncertainties and constraints which may impede the incorporation of wetland rehabilitation techniques in the province of Ontario. Specifically, attention is placed upon three factors: (1) scientific uncertainty, (2) diffusion of knowledge, and (3) institutional structure. Prior to this discussion, the strategy of wetland rehabilitation is outlined in terms of the rationale for restoration, creation and enhancement, and the present status of wetland rehabilitation in Ontario. The paper concludes by outlining a research plan to identify institutional impediments and opportunities for wetland rehabilitation in Ontario.

WETLAND REHABILITATION

The Rationale for Wetland Rehabilitation

The rationale for wetland rehabilitation has many facets. In an environmental planning and resource management context, an important development has been the realization that not only must environmental abuse be stopped, but that ecological health must be restored (Berger, 1990). This view has increased due to the fact that pristine ecosystems have become scarce. To some people it is seen as a healing technology, a form of ecological medicine, which offers the hope of reversing environmental trends (Jordan, 1985).

With the increasing awareness of the value of wetlands, there has come the realization that we should ensure a return to a more balanced ecosystem. In fact, it has been asserted that perhaps the most proactive means of demonstrating recognition of the value of wetlands is to create or rehabilitate the resource. Based upon the beneficial functions of wetlands, there are both anthropocentric (utilitarian) and non-anthropocentric (ethical) reasons for rehabilitating wetlands.

One viewpoint for advocating rehabilitation is that ethically, all species and communities have the inherent right to exist independent of human values. Another argument for rehabilitation follows the tenets of the *World Conservation Strategy*, focusing upon the maintenance of essential ecological processes and life-support systems, the preservation of genetic diversity, and the sustainable utilization of species and ecosystems (IUCN, 1980). In this vein, there has been a substantial amount of research completed which asserts that ecological restoration should be used as strategy for conserving biological diversity (Cairns, 1986; 1988; Jordan *et al.*, 1988).

There are also important human generated ecological, social and economic reasons for rehabilitating wetlands. In a life-sustaining context, wetlands provide essential ecological processes such as the moderation of air temperature, and the production of oxygen. Economically, wetlands have value in flooding protection, water quality improvement, waterfowl habitat for hunting considerations, and aesthetic appeal as well as the direct economic benefits from recreation and tourist activities (Bacon, 1987).

Rehabilitation of wetlands thus fits into the overall framework of sustainability. More specifically, rehabilitation is a sub-component of what Regier and Baskerville (1986) have termed "sustainable redevelopment". This concept emphasises the ecological rehabilitation of degraded natural environments and renewable natural resources which have resulted from the consequences of conventional exploitative development. Regier (1990) suggests that policies should seek to reverse the major abuses of the past and present, foster ecosystematic recovery even in the face of growing abuses, and initiate new technological practices. Therefore, wetlands rehabilitation is seen as a proactive strategy to achieve sustainable resource management as it ensures a return to a more balanced ecosystem to counteract the slow yet progressive impacts of technological growth.

Wetland Rehabilitation Defined

Although wetlands restoration, creation, and enhancement have been practised since the early 1900s by the U.S. Fish and Wildlife Service (Tilton, 1991), it has been the focus of concerted research only in recent years. The majority of this research has been undertaken in the United States, and to a lesser extent Europe (Kusler and Kentula, 1989a; 1989b). Wetlands rehabilitation also has been attempted in Jamaica (Bjork and Digerfeldt, 1991), India (Pandit and Fotedar, 1982) and Spain (Martinez-Taberner, 1990). In effect, these techniques have evolved out of river, lake and stream restoration practices (Gore, 1985) and the rehabilitation of degraded or damaged land primarily in Britain (Bradshaw, 1983; 1984) and the United States (Holdgate and Woodman, 1986; Jordan *et al.*, 1987).

The major impetus for widespread wetland creation activity in the United States developed from the concept of mitigation. In the early 1970s, a mitigation policy of the Fish and Wildlife Service evolved in relation to the losses of fish and wildlife habitat. The Fish and Wildlife Service developed a formal mitigation policy under the *Fish and Wildlife Coordination Act* (1981) which addressed (1) the levels and priorities for mitigation, (2) the techniques for impact analysis, and (3) selection among mitigation tools (Kinser, 1985).

The concept of mitigation can be defined in several ways. In general, mitigation is considered to include avoiding or minimizing adverse impacts and compensating for unavoidable losses. Presently, however, the most accepted definition of the concept is from the Council on Environmental Quality which defined mitigation as:

> (a) avoiding the impacts altogether by not taking a certain action or parts of an action; (b) minimizing impacts by limiting the degree or magnitude of the action and its implementation; (c) rectifying the impact by repairing, rehabilitating, or restoring the affected environment; (d) reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action; and (e) compensating for the impact by replacing or providing substitute resources or environments (as cited in Kinser, 1985).

Recently, however, wetlands mitigation has been viewed narrowly. The ability to create wetlands leads some developers and planners to interpret mitigation as allowing the destruction of an existing natural wetland and its replacement with a created wetland. Such mitigation may involve the creation of wetland within the same hydrological reach as the impacted wetland (on-site mitigation) or the construction of a replacement wetland at an off-site location. In addition, mitigation may be in-kind, where the same type of wetland that is impacted is created, or out-of-kind which involves the replacement of the impacted wetland with another type of wetland (Pierce, 1988).

A high level of interest in wetland mitigation involving creation also has been generated by regulatory agencies, environmental advocacy groups, and land developers. Regulatory agencies and environmental advocacy groups have an interest in replacing wetlands that are lost to unavoidable construction projects. Land developers are enticed by the concept of creating artificial wetlands in return for the ability to alter or destroy natural wetlands that constrain project designs. This interest led to the adoption of a "no net wetlands loss" policy within the United States with the goal that additional wetland loss will seek full mitigation on an acre-for-acre, value-for-value basis for any wetland destroyed (Bingham, 1989).

In this paper, wetlands restoration, creation and enhancement are collectively referred to as **rehabilitation**. Individually, restoration, enhancement, and creation are defined as follows (after Lewis, 1989):

Creation:

Creation of wetlands involves the conversion of a persistent non-wetland area into a wetland area by some activity of humans. Thus, created wetlands are generally regarded as constructed complexes of saturated substrates, emergent and submergent vegetation, animal life, and open water that simulate natural wetlands for human uses and benefits.

Restoration:

Wetland restoration occurs when a natural wetland is returned from a disturbed or totally altered condition to a previously existing natural condition by some action of humans.

Enhancement:

> Wetland enhancement is the increase in one or more values of all or a portion of an existing wetland by human activities.

Artificial wetland creation usually is more difficult to undertake than wetland restoration or enhancement as there is no wetland site history upon which to build. In addition, although bogs and swamps have been constructed, enhanced, and restored (Whitelaw *et al.*, 1989), most rehabilitation efforts have been directed toward freshwater and tidal emergent marshes that are aesthetically pleasing and have a high wildlife value (Coats *et al.*, 1989; Dobberteen and Nickerson, 1991). These techniques generally involve the manipulation of site specific characteristics in three major categories: (1) hydrology, (2) soil or substrate, and (3) vegetation. A review of these techniques are included in Carlisle and Mulamoottil (1990).

Wetland Rehabilitation in Ontario

As aforementioned, in the United States, wetland creation, restoration, and enhancement have become common practices to compensate and mitigate wetland losses. In Canada, however, little research on these types of rehabilitation has been undertaken, outside of the unpublished reports of Ducks Unlimited Canada. Ducks Unlimited is a non-profit conservation organization whose objectives are to preserve, restore, and develop wetlands for breeding waterfowl. As of 1988, this organization had been involved in 3,400 wetland projects across Canada ranging in size from 10 to 20,000 ha, with the total area of projects exceeding 1.3 x 10^6 ha (Neraasen, 1988).

In southern Ontario, Ducks Unlimited enters into partnerships with the Ministry of Natural Resources to develop and manage wetland habitat. Perhaps the best example of these efforts is the Hullett Marsh in Huron County where marginal farmland was converted into an extremely productive wetland (Simkin, 1989). Ducks Unlimited also enters into agreements with landowners to establish wetland sites on private property.

Canada also is committed to wetland preservation and improvement in the context of the *North American Waterfowl Management Plan* (Environment Canada and United States Department of Interior, 1986). The plan, which has a mandate to protect waterfowl habitat in Canada, has committed $1.5 billion until the year 2001 to restore waterfowl populations to 1970s' levels through wetland management and conservation.

There are, however, some isolated examples of artificial wetland establishment in southern Ontario. In the early 1980s, an experimental artificial marsh (*Typha* spp.) wastewater treatment facility was established in the Town of Listowel. This experimental system lead to a full scale marsh treatment facility in Port Perry (Herskowitz, 1986). Another example of wetland creation is that of gravel pit rehabilitation by the Grand River Conservation Authority in Bloomingdale. Known as the Synder Flats Rehabilitation Plan, this construction will enhance aquatic vegetation and wildlife in the area (Sadler, 1990). Artificial wetlands were also planned as part of Tommy Thompson Park (Leslie Street Spit) in Toronto (Kehm, 1989).

In the context of restoration, the Ministry of Natural Resources has attempted to re-establish littoral wetlands in Rondeau Bay to stabilize sediments along Lake Erie. The Maitland Valley Conservation Authority has recently completed the first year of a three year mapping project of wetlands that have the potential to be restored and have attempted to restore a five acre wooded swamp in Howick Township (MVCA, 1990). In addition, the St. Clair Region Conservation Authority has attempted to restore an eighteen hectare marsh within the Town of Strathroy (SCRCF, 1990). Finally, there have been isolated attempts at rehabilitating degraded urban wetlands. This strategy has been undertaken in enhancing the Oshawa Second Marsh and Rattray Marsh in the City of Mississauga (Whillans, 1987).

Although wetland creation efforts in southern Ontario are limited, there are signs that this strategy will increase in importance in the next few years. Recently the *Final Report of the Great Lakes Wetlands Policy Consortium* was released and contains fifty recommendations on wetland preservation and management (Brown, 1990). Recommendation forty-four states that there should be an increase in the quality and quantity of wetland resources through restoration of previously filled, drained, or polluted wetlands and through the creation of wetlands in appropriate places.

The report outlines a series of steps that should be followed to implement this recommendation (Brown, 1990):

- Identify a source of financial, logistical and political support for the wetland restoration/creation project. Take advantage of existing programs and procedures which provide opportunities for wetland restoration and creation.

- Prioritize sites for wetland restoration/creation on the basis of past losses and need for wetlands in the area, so that heavily disturbed areas with poor water quality and a majority of wetland areas filled, drained or disturbed receive high priority.

- Investigate the hydrology, geology, biology and past history of the restoration/creation site prior to any action, to determine the wetland type which is appropriate for that site.

- Plan the restoration/creation project based on a standard set by a natural 'reference' wetland of the same type for the project site.

- Use best current methods at the restoration/creation site to imitate slopes, soils, hydrology and vegetation of the natural wetland standard. And,

- Evaluate the restored/created wetland against the 'reference' wetland immediately after completion and two years later, and take necessary steps to correct any problems. Set up a long-term monitoring program and identify management needs to insure that the wetland functions like a natural wetland; set aside funds for management and monitoring.

However, if wetland restoration, enhancement and creation are to become widespread as opposed to incremental, there is a need to increase the cooperation and communication among those active in the field of restoration ecology. In addition, the management philosophy will have to change from one of reactive preservation and conservation to one of proactive rehabilitation. It appears that the lack of a concerted effort towards wetland rehabilitation in Ontario is a result of three major factors: scientific uncertainty, problems in diffusion of knowledge, and the absence of institutional mechanisms. Each of these variables are discussed in the following sections.

UNCERTAINTIES AND CONSTRAINTS IN WETLAND REHABILITATION

Impediments to the infusion of widespread wetland rehabilitation in Ontario can be classified as information barriers and structural barriers (Blaikie, 1978). We see both scientific uncertainty and information dissemination as information variables and the present institutional framework for wetlands management as a structural variable.

Scientific Uncertainty

The development, improvement and re-establishment of wetlands in North America is in its infancy and is largely in an experimental stage. A lack of scientific data on the long-term success of creation projects is a major source of uncertainty and has led some researchers to conclude that wetland rehabilitation should not be routinely used as a means of natural wetland compensation (Race, 1985). However, some researchers such as Erwin (1989) have argued that the feasibility of rehabilitating wetlands is adequately demonstrated, but the refinement of techniques is still needed. Therefore, in order to improve the cost-effectiveness and overall success rate of rehabilitation projects, a better understanding of fundamental ecological processes such as succession, nutrient cycling, predation, competition and of the interaction of biotic and abiotic factors is required (Ecological Society of America, 1991).

A major objection to artificial wetland construction is that new wetlands do not function in the same manner as natural wetlands. The morphological similarity of artificial wetlands is no longer accepted as a successful creation project. Hence, the case for establishing wetlands for aesthetic reasons alone is no longer supported. Success is now related to sustaining the hydrological, biological, and chemical processes that characterize the ecosystem's overall ability to function (Larson, 1988). However, a second major source of scientific uncertainty exists because limited research has been conducted to determine if and when these functions and biological diversity are effectively replaced.

Diffusion of Knowledge

The problem of scientific uncertainty is a part of the larger impediment of information dissemination. While wetland rehabilitation is undertaken routinely south of the border, Ontario and the rest of Canada seem to be lagging behind. One then has to wonder if a constraint to wetland rehabilitation is based upon information diffusion.

If wetland rehabilitation can be conceptualized as an innovation, innovation-diffusion literature may be of some assistance. An innovation can be defined as,

> ...the successful introduction of ideas or artifacts, perceived as new, into a given social system. It may be based on an idea or prototype that is invented, borrowed or imitated. Essentially, as long as it is recognized as new in a given area, it is an innovation (Bradford and Kent, 1977, 128).

Any action that imitates the first innovation is characterized as adoption. Diffusion of innovations over geographic space and time are a function of the processes of adoption and information dissemination. The time lag that occurs between the time of the first innovation and widespread adoption may represent a technological gap where the actual use of available technology is substantially less than potential use (Meek, 1990).

Hägerstrand (1967) has suggested that in reality few people can be expected to accept and embrace an innovation upon initial contact with it. This so-called "resistance" within a population thus acts like a barrier to the diffusion of an innovation and may be based on various economic, psychological or social reasons (Morrill and Manninen, 1975). There is no doubt, however, that information dissemination is a critical factor affecting diffusion (Meek, 1990).

The mode of information transfer will determine who has access to that information. Do those who receive the information pass it along? Clearly as the number of adopters increases, the probability of the adoption also increase. Through this "bandwagon effect" uncertainty surrounding the innovation diminishes (Meek, 1990).

It is argued that wetland rehabilitation as an innovation within the context of Ontario is currently impeded by a concentration of knowledge within a relatively small number of practioners in government agencies and non-government organizations. As a result, the province is in a time lag between first innovation and widespread adoption. Information must be disseminated throughout the province. The *Final Report of the Great Lakes Wetland Policy Consortium* attempts to do just that. Perhaps the OMNR's wetland information program could also incorporate and promote wetland rehabilitation such that other departments and ministries, landowners, industries, planning authorities and the general public become aware of the importance of restoration, creation and enhancement of wetlands.

Institutional Uncertainty

It has been generally conceded that the failure to fully comprehend and appreciate the complexity of institutional arrangements is one of the largest impediments to the successful implementation of resource policy. In fact, some have gone so far as to say that institutional impediments are more prominent, perplexing and persistent when compared to physical, economic and technical problems (Ingram *et al.*, 1984). Institutional arrangements are of critical importance as they set the conditions under which resources may be managed and perhaps more importantly, who manages them. In addition, these arrangements affect the implementation of resource policies and structure the policy making process (Mitchell, 1989).

The present institutional arrangement for wetlands management is extremely complex. Internationally, Canada has made several commitments to support wetlands protection. On 15 January 1981, Canada endorsed the Ramsar Convention (1971), the *International Conference on Conservation of Wetlands and Waterfowl*. In consultation with Ontario, Canada has nominated several wetlands within the province under the Ramsar Convention. These include Long Point Provincial Park, the St. Clair

National Wildlife Area, and Polar Bear Provincial Park. Canada also is committed to wetland preservation and improvement in the context of the *North American Waterfowl Management Plan* (Environment Canada and United States Department of Interior, 1986) and is a member of the General Assembly of the International Union for the Conservation of Nature and Natural Resources which passed a resolution in 1988 urging governments and development assistance institutions to require that environmental impact assessments be completed prior to actions that will significantly affect the ecological character of wetland ecosystems (Ontario Ministry of Natural Resources, 1989).

The federal government is preparing guidelines to aid the provinces in wetland management within the context of formulating policies for the identification and protection of wetlands (Environment Canada, 1989). These guidelines were developed in consultation with several agencies such as Wildlife Canada, the Federation of Ontario Naturalists, in addition to the various provincial representatives. This policy, which is currently awaiting Cabinet approval, will encompass the protection, enhancement, and use of wetland environments such that the highest long-term social, economic and ecological benefits are attained. The policy recognizes that some wetlands should be conserved and protected in their natural condition, some managed to allow for sustained compatible use of renewable wetland resources, and some developed for their non-renewable resources.

The federal government also has a non-voting member on the nine member North American Wetlands Conservation Council which was established on 13 December 1989 under the United States *North American Wetlands Conservation Act*. In addition, a national policy forum was convened in mid April 1990 by the National Round Table on the Environment and the Economy that focused on sustainable wetland benefits for Canada. The purpose of this forum was to develop recommendations on how the public and private sectors can effectively contribute to sustaining wetlands. The Canadian Wetlands Conservation Task Force was formed to evaluate and identify appropriate action strategies for these recommendations under the auspices of the North American Wetlands Conservation Council (Canada) (NAWCCC, 1991).

Federal involvement also occurs by Environment Canada through the provisions of the *Canada Wildlife Act*, the *Migratory Birds Convention Act*, and the *Canada Fisheries Act* (Whillans, 1987). Environment Canada's interest in wetland management lies primarily in the protection of fisheries and wildlife habitat (Ontario Ministry of Natural Resources, 1989). In Canada there also has been the development of wetland conservation programs to aid in the inventorying of wetlands as well as to help in the decision-making process. The former Prime Resource Lands Component of the Canadian Land Use Monitoring Program of the Lands Directorate considered land use change as it effected wetlands in Canada . This program led to several wetland studies in various parts of Canada (*e.g.*, Lynch-Stewart, 1983). The government of Canada also has developed a wetland classification system (Environment Canada, 1987).

Primary responsibility for wetland management is vested within the provinces. Although there is no legislation that is specifically devoted to wetlands, there are several laws in Ontario which affect wetland management and conservation both directly and indirectly (Table 10.1). These pieces of legislation, though incompletely coordinated, provide for various mechanisms affecting wetlands including agricultural land drainage, restrictions on development activities within or surrounding wetlands, land acquisition, donations, leases and easement of property where wetlands are located, and prosecutions and fines if the resources is degraded. Reviews pertaining to this legislation and the various mechanisms are provided by Dahme (1989) and Maynard (1989).

In Ontario, a key ministry responsible for wetlands is the Ministry of Natural Resources (OMNR). The OMNR is responsible for overall policy direction, technical information, and assistance in interpreting baseline data obtained from the administration of the Wetland Evaluation System (Environment Canada and Ontario Ministry of Natural Resources, 1984). The OMNR's concern about wetland loss resulted in the development of an extensive wetlands program since the early 1980s. From an initial discussion paper (Ontario Ministry of Natural Resources, 1981), guidelines were developed for wetland management in 1984 (Ontario Ministry of Natural Resources, 1984). These guidelines were subsequently replaced by the Wetlands Planning Policy in 1989 (Ontario Ministry of Natural Resources, 1989) and the more recent Wetlands Policy Statement (Ontario Ministry of Natural Resources and Ontario Ministry of Municipal Affairs, 1991). Presently, the OMNR's wetlands program consists of six components: (1) wetland inventorying and evaluation; (2) land use planning; (3) wetland securing efforts including cost-sharing agreements with non-governmental organizations; (4) the *Conservation Lands Act*; (5) wetland research; and (6) a strategy for communicating wetland information to the public (Ontario Ministry of Natural Resources, 1988).

TABLE 10.1
Provincial Legislation Related to Wetlands in Ontario

Planning Act
Municipal Act
Conservation Lands Act
Conservation Authorities Act
Drainage Act
Tile Drainage Act
Public Lands Act
Ontario Heritage Act
Ministry of Government Services Act
Provincial Parks Act
Environmental Assessment Act
Environmental Protection Act
Ontario Water Resources Act
Endangered Species Act
Game and Fish Act
Lakes and Rivers Improvement Act

Source: Dahme (1989); Whillans (1987)

Sections of the *Planning Act* (1983) provide for the protection of the natural environment, features of significant natural interest, and matters of provincial interest. More specifically, Section 3 of the *Act* provides for policy statements to define the provincial interest in greater detail. It is under this authority that the *Wetlands Planning Policy* (1989) and the Wetlands Policy Statement (1991) were issued. Through the *Wetlands Planning Policy*, wetland conservation will be infused into the land use planning process. Provincial ministries and local municipalities in general must follow policy statements unless it is demonstrated that the policy is not applicable or less applicable. The policy statement does not in itself assure wetland protection but, rather, is one element in an overall wetland conservation strategy for the province of Ontario (Ontario Ministry of Natural Resources, 1988; 1989).

The policy statement does not in itself assure wetland protection but, rather, is one element in an overall wetland conservation strategy for the province of Ontario. At this time the policy and the "Implementation Guidelines" have not received final approval under the *Planning Act* and hence, do not have any formal status (Lindgren, 1991). In addition, this document has been criticized by several organizations for several reasons. It does not address agricultural activities that contribute to losses and degradation. It does not make mandatory changes in the way institutions view wetlands. It fails to confer adequate protection upon provincially, regionally, or locally significant wetlands. Finally, there is no provision for wetlands restoration (Lindgren, 1991).

As indicated earlier, the Ontario Ministry of Municipal Affairs (OMMA) is an important agency in wetland management. However, several other provincial ministries also have responsibility for wetland management. The Ontario Ministry of the Environment (OMOE) is responsible for the protection of air, water, and land resources. Thus, with respect to wetlands the OMOE has an interest in hydrology as it relates to water quality, low flow and groundwater. The Ontario Ministry of Agriculture and Food (OMAF) has the responsibility for administering the *Foodland Guidelines* which are directed at maintaining Ontario's agricultural land base to ensure that other land uses in agricultural areas are compatible with agriculture. OMAF also is responsible for implementing an array of legislation and other policies which have impacts on wetlands, primarily agricultural land drainage under the *Drainage Act* and *Tile Drainage Act*.

Where Conservation Authorities exist, they are responsible in part for wetland acquisition, designation of scheduled areas and other matters involving wetlands which pertain to the overall watershed under its authority (Ontario Ministry of Natural Resources, 1989). Wetland preservation and conservation is implemented primarily under the powers afforded to the authorities under Section 28 of the *Conservation Authorities Act* which is to initiate and enforce regulations which govern the fill, construction and alteration to waterways especially as it relates to flooding. Conservation authorities, such as the Grand River Conservation Authority, also have prepared integrated planning principles and master plans to ensure the protection of wetlands within its watershed boundaries in addition to working closely with municipalities to incorporate wetlands into Official Plans and into open space areas in subdivision plans (Veale *et al.*, 1991).

Local government involvement in wetland management is undertaken under the auspices of the *Planning Act*. Municipalities and planning boards are responsible for preparing official plans, zoning by-laws and other planning documents to control land uses within their jurisdiction. This is completed within the context of social, economic, and environmental factors (Ontario Ministry of Natural Resources, 1988). Several non-government organizations also have a vested interest and involvement in wetlands and have adopted their own wetlands policy (Federation of Ontario Naturalists and Environment Canada, 1987; Ontario Ministry of Natural Resources, 1989). These non-government organizations include Wildlife Habitat Canada, Federation of Ontario Naturalists, Ontario Federation of Anglers and Hunters, Nature Conservancy, Natural Heritage League, and Ducks Unlimited Canada.

If Ontario is to become involved in wetland rehabilitation projects as advocated by the Great Lakes Wetlands Policy Consortium, it is unclear where such initiatives will fit into the complex institutional arrangement for wetland resources outlined above. Currently there are over twenty pieces of legislation, a six point program administered by the Ministry of Natural Resources, a non-government organization policy, and two wetland policies at three levels of government that directly or indirectly affect wetlands. No policy or piece of legislation has a provision for any type of wetland rehabilitation. This must be addressed before any serious attempts at wetland rehabilitation can proceed.

FUTURE RESEARCH STRATEGY

In the absence of an effective institutional mechanism for wetland rehabilitation in Ontario, several problems and questions emerge. These include:

(1) Are landowners going to be receptive when told that a parcel of their land has been identified as a high priority rehabilitation area?

(2) What will it take for landowners to participate in rehabilitation projects? What incentives are needed?

(3) What are the attitudes and perceptions of those in government and non-government organizations?

(4) What agencies and ministries have to become involved?

(5) Which institutions will bear the costs during and after rehabilitation?

(6) Will rehabilitation be integrated into the present institutional arrangements or will a new policy or piece of legislation be developed?

With these questions in mind, a research project has been initiated at the University of Western Ontario to examine the acceptability and feasibility of a formal strategy for wetland restoration, enhancement and creation in southern Ontario. Specifically the objectives of the project are to:

(1) inventory the extent of wetland rehabilitation in the province;

(2) examine the present institutional arrangements for wetlands management in Ontario;

(3) elicit landowner, non-government and government opinion on the feasibility and need for revisions to the present institutional arrangements to incorporate wetland rehabilitation; and

(4) propose recommendations for an institutional arrangement for wetland management, conservation, and rehabilitation in Ontario.

To study the barriers to and opportunities for the integration of wetland rehabilitation into the present institutional structure, an analytical framework developed by Mitchell (1987) and subsequently modified by Smith (1992) will be utilized. The framework has five aspects or leverage points where opportunities exist to improve integration within a overall context: legitimization, functions, structures, processes and mechanisms, and organizational culture and participant attitudes. Detailed descriptions and rationale for the choice of these leverage points are found in Mitchell, (1987), Smith (1992), and Mitchell and Shrubsole (1992). The leverage points are not related in a hierarchical manner but, rather, in an iterative fashion wherein changes to any one component are likely to affect other aspects of the system. The analysts should be aware that some mix of these points are needed to enhance effectiveness. Thus, by examining five key "leverage points" that provide the potential for change, the inter-relationship of several variables can be examined within the overall context of society, the environment and the economy.

Methodology

The methodology employed in the study will rely on the collection of information and data through the use of three techniques. These techniques are: (1) an extensive literature review, (2) the administration of a questionnaire, and (3) the use of elite interviews.

The first objective of the study, that is, to determine what the current status of wetland rehabilitation techniques and experience in southern Ontario will be fulfilled through a literature review. In addition, the literature including legislation, policies, regulations and official plans will provide the required data to input into the analytical framework to describe the current institutional arrangements for wetlands management in southern Ontario. From this examination, opportunities and constraints to wetland rehabilitation will be obtained.

Based upon the results of the descriptive analysis of present institutional arrangements, a series of summary statements and questions involving wetland rehabilitation will be formulated for each leverage point in the analytical framework. Although it is difficult to tell at this time exactly what these might be, the major focus will be on suggesting ways in which a rehabilitation policy, law or program might be incorporated into Ontario. For example, it might be found that the best method would be create a new piece of legislation or that restoration, enhancement, and creation should be incorporated into the current wetlands policy. Another potential solution may be to create a wetlands restoration program within the Ministry of Natural Resources.

The statements proposed will then be presented to several different stakeholders with an interest and responsibility for wetland management, conservation, and preservation within the province of Ontario through the use of a questionnaire. The questionnaire will be used to elicit reactions and responses to the proposed changes at each leverage point. The survey will include a sample of various stakeholders such as individual landowners, local municipalities (township level), regional municipalities, conservation authorities, environmental consultants, non-government agencies, government officials, and individual experts.

In order to determine the support of rural landowners, three watersheds will be used as the sample, as opposed to the political boundaries used in previous attitude studies towards wetlands. The watersheds tentatively selected are the St. Clair Region Conservation Authority, the Maitland Valley Conservation Authority, and the Grand River Conservation Authority. These watersheds have been chosen on the basis of their high rural agricultural base and the disparity in total wetland loss. Past experience with wetland rehabilitation projects within the watershed also influenced the selection of these three authorities. Furthermore, they are different in areal extent which may provide interesting differences (*e.g.*, farm size).

Not all of the actual key individuals in the other various groups have been identified at the present time. However, it is anticipated that twenty individuals from each class will be surveyed to form a sample group of 140. The same questions regarding the feasibility of the consensus statements involving wetland rehabilitation will be asked. These questions will include reactions and responses concerning,

- the feasibility and desirability of wetland restoration, creation and enhancement;
- the need for incentives;
- what institutions should have management responsibilities;
- who should pay for wetlands rehabilitation;
- which functions should be or should not be rehabilitated; and

- what problems are perceived in restoration, creation, and enhancement of wetlands.

After the results of the questionnaire technique are finalized, the data will be used to prescriptively in the analytical framework to propose normative suggestions on how to incorporate wetland rehabilitation into the present institutional framework for wetlands. Subsequently, interviews with ten to fifteen key decision makers in the Federal and provincial government will be undertaken to discuss the recommendations.

CONCLUSION

Despite several conservation, management, and wetland acquisition programs developed within Canada and the province of Ontario, the conversion of wetland ecosystems to other land uses continues and, in some instances, is promoted and funded by provincial agencies. Current policies and legislation do not consistently deal with wetland uses and wetland destruction continues. Thus, widespread wetland rehabilitation is required to compensate for historical losses and to mitigate current losses and degradation caused by development. This would ensure the ecological sustainability of the resource base.

Although there are definite scientific and informational impediments to wetland rehabilitation in Ontario, it is argued here that institutional arrangements are the critical factor in this facet of resource and environmental decision making. There is an inextricable linkage between the policies and programs that governments develop and the institutional arrangements and concomitant processes that exist to implement these policies and programs. In essence, the institutional milieu determines the success or failure of a policy or program as well as their very existence (Hartmann and Donahue, 1990). It is therefore imperative that a holistic study of the institutions, institutional processes and institutional arrangements that will affect wetland rehabilitation be undertaken to identify the opportunities and impediments to this strategy.

Finally, it is important to note that while wetland creation, restoration, and enhancement are feasible objectives, it is essential that these efforts do not supersede the preservation, conservation, and sound management of 'natural' wetland resources. Improved technical capabilities and public acceptance of strategies for rehabilitating wetlands should not undermine the argument for retaining natural systems. Wetland rehabilitation should be seen as a method of augmenting and upgrading the resource base, not an endorsement to degrade or destroy existing natural ecosystems.

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CHAPTER 11

COPING WITH THE UNCERTAINTIES AND CONFLICTS OF NITRATE POLLUTION IN THE U.K.

Nigel Watson

INTRODUCTION

The problem of nitrate pollution from agricultural sources is currently attracting much attention in the United Kingdom (U.K.). Changes in agricultural policies and technologies over the last fifty years have increased the productivity and improved the efficiency of farming practices dramatically. However, as one observer has commented, "the agricultural industry has been too efficient for its own good" (Jones, 1987, 60). There is now increasing concern about the possible adverse environmental effects of modern farming practices. As a result, a number of conflicts among agriculture and other resource interests have developed in the U.K. The nitrate problem is a significant example of these conflicts, and involves issues of concern to farming, water management and environmental interests.

Although nitrate pollution is itself a bio-physical phenomenon, the conflict also is rooted in the institutional arrangements for the management of both agricultural and water resources. As such, the nitrate issue raises important questions about land-water interactions, and about how these resources can be managed to provide an adequate food supply while at the same time meet water management objectives. For the purpose of clarity, institutional arrangements are defined here as "those structures, processes and policy approaches for making public decisions and for influencing the behaviour of private individuals, groups, and firms" (Mann, 1983, 116).

Considerable uncertainty exists regarding the risks and causes of nitrate pollution. Perceptions of the problem vary among the various participants with stakes in the nitrate issue. As a result, the question of how the problem should be resolved has proved to be particularly contentious. This paper examines the nitrate issue in the U.K. and is divided into three main sections. The first section addresses the nature of the problem, and identifies the main areas of the uncertainty. The second section focuses specifically on key aspects of the institutional arrangements which relate to the management of nitrate pollution. The third section presents conclusions regarding the significance of uncertainty and conflict in the development of institutional responses to the nitrate problem in the U.K.

NATURE OF THE PROBLEM

Rising levels of nitrate in both surface and groundwater have been observed in the U.K. during the last twenty years. The most significant increases have been experienced in the lowland areas of England, and approximately 100 groundwater sources in the Severn-Trent and Anglian water management regions are affected (Department of the Environment, 1986). The extent of the problem is illustrated by figures for 1987 which indicated that 850,000 people received drinking water during that year which regularly exceeded the 50 mg/litre nitrate limit (House of Lords, 1989). For many groundwater sources, nitrate levels are expected to continue to rise for the next twenty or thirty years due to the slow downward movement of nitrates already in the soil. Further increases in nitrate levels in water are expected over the long term if present agricultural practices continue. This trend of increasing nitrate levels is of concern because of possible hazardous consequences for public health and the aquatic environment.

Nitrate as a Public Health Hazard

A major concern associated with nitrates in drinking water is the risk of infantile methaemoglobinaemia (blue baby syndrome). Consumed nitrate can be converted to nitrite in the body, which may react with haemoglobin in the bloodstream to produce methaemoglobin. Methaemoglobin reduces the supply of oxygen to the brain and other tissues, and in extreme cases can lead to death. Although the condition is rare and only 3,000 cases have been reported worldwide since 1945 (House of Lords, 1989), concern exists that the predicted increases in nitrate levels could place infants at greater risk in the future.

A second concern is the possible link between nitrate and stomach cancer (Fraser *et al.*, 1980). A study by Hill *et al.* (1973) found an increased death rate from stomach cancer in the English town of Worksop, where the public water supply contained high concentrations of nitrate. Evidence from other studies (*e.g.*, Beresford 1985) does not support the nitrate-cancer link in humans, although a link has been established in experimental work with mice. However, there is also considerable theoretical evidence to show that the link is possible in humans (Walters, 1984). Other possible risks of nitrate and nitrite have been investigated. For example, Shuval and Gruener (1972) reported lowered growth and reduced brain activity in rats exposed to high doses of nitrite, which raises questions about possible sub-clinical effects in humans. Overall, current evidence of the epidemiological and toxicological risks associated with nitrate consumption is inconclusive (Magee, 1982).

Nitrate as an Environmental Hazard

In addition to concerns about public health, nitrate pollution is regarded by some interests as a problem due to environmental effects such as eutrophication and the growth of blue-green algae. Considerable uncertainty exists regarding the relative roles of nitrate and phosphate in the eutrophication of fresh and marine waters, and different views of the risks have emerged. For example, in the U.K. the Nitrate Coordination Group concluded that "there is little evidence that nitrate concentrations are causing ecological harm to rivers, estuaries or the sea" (Department of the Environment, 1986, 74). In contrast, the European Commission regards the threat of eutrophication within the European Community (EC) to be more serious, and has recently placed a requirement upon Member States to take actions to prevent nitrate contamination of the aquatic environment in general.

Causes of Nitrate Pollution

Further uncertainty exists regarding the precise causes of rising nitrate levels. A number of nitrate sources may be involved, including fertilizers, livestock manure, sewage, and silage effluent (Royal Society of London, 1982). Several major investigations have been completed on nitrate pollution in the U.K., including the Royal Commission on Environmental Pollution (1979), the Royal Society of London (1982), the Nitrate Coordination Group (Department of the Environment, 1986), and the House of Lords (1989). There is general agreement among the reports that changes in agricultural practices over the last fifty years have contributed to the nitrate problem. However, there is considerable variation in the recommendations made in the reports, reflecting in part the uncertainty which surrounds the nitrate issue. Available figures for fertilizer use certainly point towards this as a likely source of the nitrate problem. Between 1963 and 1983, the annual use of nitrogen fertilizer in the U.K. rose from 530,000 tonnes to 1.6 million tonnes (Department of the Environment, 1986).

Uncertainty is particularly apparent regarding groundwater contamination. Groundwater is an important resource in the U.K. and is used for approximately 50% of public water supplies in the Midlands and Anglian regions of lowland England. Intensive farming practices are common in these regions. As a result, there is considerable potential for nitrate contamination of groundwater where the aquifer is unconfined. Present contamination levels may reflect agricultural conditions 20 or 30 years ago due to the slow response times of the aquifers. It is therefore uncertain what effects more recent farming activities will have upon future nitrate contamination levels. It appears likely that a number of factors have contributed to the problem, including the ploughing up of grassland and the use of nitrate fertilizers. However, there is disagreement regarding the relative importance of each source. Agricultural scientists such as Addiscott (1988) have pointed out the complexities of nitrate behaviour in soil, and have argued that reductions in nitrate fertilizer applications alone may not reduce leaching losses, but may bring hardship to farming communities. It is not surprising that farming lobby groups have used these arguments against various proposals to deal with the nitrate problem at source.

In summary, uncertainty is a key feature of the nitrate issue in the U.K. Evidence of the health and environmental effects of nitrate is at present inconclusive, and perceptions of the risks vary among the key water and agricultural interests. There is little doubt that rising levels of nitrate are due to changes in agricultural practices over the last fifty years, but opinion is divided regarding the key bio-physical processes and the likely effects of measures designed to limit nitrate loss from the soil.

INSTITUTIONAL ARRANGEMENTS

The uncertainties of nitrate pollution have important institutional implications. One consequence of the present limited understanding is that it is unclear how institutions should respond to the nitrate problem. In the absence of conclusive evidence, an argument can be made for not responding at all. There is some evidence of this happening in the U.K. For example, the early 1970s to late 1980s has been characterized as a period of non-decision making with respect to nitrates (Hill *et al.*, 1989). However, it is becoming increasing clear that uncertainty is an ever present feature of water resource management and as Holling (1978, 5) argued, "attempts to eliminate uncertainty are delusory and often counterproductive". It is therefore important that resource management institutions are capable of responding to problems despite uncertainty, taking action in some directions while waiting for improved understanding in others.

An evaluation of institutional responses to the nitrate problem in the U.K. is presented in the following sub-sections. Attention is focused on three key institutional elements of the responses: structures and functions, management approaches, and organizational culture.

Structures and Functions

Institutional structures and the arrangement of functions within those structures can have important consequences for resource management. Resource issues frequently overlap the jurisdictions and interests of a number of agencies and groups, and there is potential for "boundary problems" such as fragmentation and conflict (Mitchell, 1990, 5). In order to develop effective institutional responses to particular issues or problems, it is important that structures and functions are designed to facilitate coordination.

There is evidence of boundary problems existing between two central government ministries which have policy responsibilities relating to nitrates. The Department of the Environment (DoE) has responsibilities for government policy on a wide range of issues, including planning, housing, local government, and the environment (Gaskell and Tanner, 1991). The DoE is also responsible for water management and water pollution control policy. The Ministry of Agriculture, Fisheries and Food (MAFF) is responsible for government agriculture policy and aims "to foster an efficient and competitive agriculture industry" and to "achieve a reasonable balance between the interests of agriculture, the economic and social interests of rural areas and the conservation of the countryside" (MAFF, 1990, 1). As such, MAFF also has environmental duties, including the prevention of nitrate pollution.

The overlap of responsibilities between the DoE and MAFF has resulted in conflict. The House of Commons Environment Committee reported on the nitrate issue as part of an investigation of the pollution of rivers and estuaries in 1987. On the basis of both written and oral evidence, the Committee stated that for nitrates it was "apparent that there is some disagreement between the DoE and MAFF on how best to proceed" (House of Commons, 1987, para.79). While the DoE has advocated the establishment of nitrate protection zones, MAFF has favoured an approach involving more research and the use of curative water treatment measures.

The conflict between DoE and MAFF over nitrates results from a longer-running battle for primacy over pollution control policy in the agricultural sector. During the 1980s and early 1990s, the DoE introduced a series of regulatory measures to deal with water pollution from municipal and industrial sources. However, MAFF has maintained control of environmental policy within the agriculture sector, and has developed an approach to dealing with farming-related pollution based on the provision of advice and encouragement rather than regulation. As such, agricultural pollution has emerged as a 'special case' under MAFF control which is not subject to the same degree of regulation as other sources of water pollution.

One of the most significant attempts to overcome the divisions between the DoE and MAFF was the establishment of the Nitrate Coordination Group in 1985. Membership of the Group was drawn from the DoE, MAFF, and a range of organizations representing the water and agriculture industries. The Group's terms of reference were to "provide a forum for the evaluation of information collected on the sources, pathways and concentrations of nitrate in water, and the extent of the problem, to identify research needs, and to consider action to reduce or limit nitrate concentrations in water supplies' (Department of the Environment, 1986, 1). The Group's report provides a comprehensive review of the nitrate problem in the U.K. but concludes that the Group was unable to resolve the conflicting issues among water and farming interests.

There is some evidence of improved cooperation and coordination between the DoE and MAFF in the late 1980s and early 1990s. For example, the two ministries cooperated by giving joint evidence to the 1989 House of Lords inquiry on nitrate in water. Indeed, one representative of MAFF stated at the time that 'there is a very close identity of view between the two Departments' (House of Lords, 1989, 27). However, while relations may have improved between the two bodies, other evidence indicates that important differences of opinion remain. For example, the National Rivers Authority (NRA) has argued that regulatory measures should be introduced immediately to control agricultural sources of nitrate. The NRA operates under the arms-length control of the DoE. In contrast, MAFF has advocated a more cautious experimental approach to dealing with agricultural sources of nitrate.

In summary, the division of responsibilities between the DoE and MAFF continues to be an important source of conflict in the development of policies to deal with the nitrate problem. MAFF has remained largely in control of measures to deal with agricultural pollution, including nitrates. While it has attempted to balance agricultural production aims with environmental considerations, MAFF has come under increasing pressure from water and environmental interests to develop a stronger regulatory approach towards agricultural pollution. Measures which have been introduced to deal with the nitrate problem are discussed in the following section.

Management Approaches

One of the most significant developments in the European Community (EC) regarding nitrates in the 1980s was the introduction of the 50 mg/litre EC Drinking Water Standard. It is important to stress that the EC standard is a maximum admissible limit and not a guideline or average figure. Prior to implementation of the EC Standard in 1986, water suppliers in the U.K. had operated according to the 100 mg/litre nitrate limit set by the World Health Organization (W.H.O.) (Wilkinson and Greene, 1982). While few water sources had exceeded the W.H.O. limit by the 1980s, many had nitrate concentrations above 50 mg/litre. As a result, the nitrate issue emerged as a major concern and source of conflict following the introduction of the more stringent EC standard.

The British Government opposed the lowering of the nitrate standard on the argument that the medical evidence does not support such a stringent and inflexible limit. To this effect, the Chief Medical Officer issued a letter in 1985 stating that only where the water supply exceeds 100 mg/litre should alternative sources be provided for infants. The letter also discounted claims of a link between nitrate and stomach cancer. The U.K. Government took steps in 1985 to avoid full implementation of the EC nitrate standard. Forty-eight exemptions (termed 'derogations') were issued to water suppliers in England allowing water to be supplied which regularly exceeded the EC limit. However, under the threat of legal action in the European Court, the U.K. was forced to withdraw the derogations and comply with the EC standard for drinking water in 1988 (*The Times*, April 11, 1988).

Until recently, the U.K. response to the enforced EC nitrate standard has been based on the implementation of curative water treatment measures. Where possible, contaminated sources are being blended with other higher quality sources before being used for public water supplies. In locations where high quality sources for blending are unavailable, de-nitrification technology is being installed. It is significant that the considerable costs of these curative measures fall upon the water industry and water consumers. To keep water supplies below 50 mg nitrate/litre over the next twenty years, cumulative capital expenditure for the water industry has been estimated at the equivalent of $400 million. This expenditure would secure water supplies for 4.6 million people (DoE, 1986).

The privatization of the water industry in England and Wales in 1989 had important implications for the control of nitrate pollution. The water supply and sewage treatment functions of the ten multi-functional Water Authorities (WAs) were transferred to private sector companies. As a result, the costs of lowering nitrate levels using water treatment measures are no longer absorbed by the public sector. Additional water management functions, such as pollution control and flood prevention were transferred from the WAs to the National Rivers Authority (NRA). The NRA has wide ranging duties for the protection of the water environment in England and Wales. One consequence of these institutional changes was that greater emphasis was placed on the introduction of measures within the agricultural sector to prevent nitrate pollution.

Prior to water privatization, little preventative action had been taken to deal with nitrate pollution. MAFF's approach to pollution prevention was based on guidelines set out in a Code of Good Agricultural Practice. During the 1980s, MAFF's approach was the focus of considerable criticism. For example, the House of Commons Environment Committee (1987, para. 62) stated that "MAFF's failure to take farm pollution seriously is encapsulated in its ineffective approach of positive encouragement".

There was a moderate change of approach following the introduction of the 1989 *Water Act*. The *Act* contains provisions for the designation of Nitrate Sensitive Areas (NSAs), and the regulation of farming practices within these areas. It is significant that MAFF has policy responsibility for the NSAs Scheme, which was introduced on an experimental basis in ten small farming areas in 1990 (Table 11.1). The NSAs Scheme operates on a voluntary basis, and farmers receive payments for introducing changes to agricultural practices and land use. MAFF justified the limited introduction of NSAs on the basis that agricultural restrictions should be tested prior to wider application since the effects on nitrate levels in water are uncertain. In contrast, the NRA has criticized the NSAs Scheme because, in its view, it involves only voluntary measures which do not provide a sufficiently secure basis for preventing nitrate pollution (*The Times*, August 2, 1989).

Two further policy initiatives to prevent nitrate pollution are particularly important. The first is an EC Directive which was introduced in 1991. It requires Member States to designate vulnerable zones where water is likely to contain more than 50 mg nitrate/litre if preventative action is not taken. Member States have four years to introduce compulsory restrictions on the use of nitrogen fertilizers within the vulnerable areas. This Directive

TABLE 11.1
Uptake of Nitrate Sensitive Areas Scheme

Area	Estimated Total Agricultural Land (Ha)	Basic Scheme (% land)	Basic Scheme (% total farmers)	Premium Scheme (%land)
Ogbourne St George	984	72.4%	80.0%	10.8%
Kilham	756	37.9%	66.6%	0.0%
Egford	427	51.5%	46.2%	9.8%
Old Chalford	621	93.1%	83.3%	26.6%
Wellings	523	61.8%	58.3%	1.7%
Tom Hill	570	82.3%	68.0%	3.3%
Wildmoor	723	94.7%	86.8%	1.9%
Boughton	1,652	98.5%	95.2%	1.0%
Sleaford	2,876	100.0%	100.0%	32.8%
Branston Booths	1,592	99.6%	95.5%	13.1%
TOTAL ALL NSAs	10,724	87.3%	79.8%	14.2%

Adapted from Ministry of Agriculture, Fisheries and Food, News Release 196, 1991.

is presently the cause of considerable concern among U.K. farmers and has generated conflict because it may result in large areas of lowland England being designated as vulnerable zones. One of the main objections of agriculturalists to the Directive is that it emphasizes restrictions on fertilizer use, which they do not believe will check the long-term trend of increasing nitrate levels in groundwater.

A second policy initiative concerns plans by the NRA to designate groundwater protection zones. Although the proposals are presently at a consultation stage, it appears likely that further measures will be developed to restrict agricultural activities which may contaminate groundwater within these zones.

The U.K. approach to dealing with nitrate pollution has evolved through three distinct phases. Prior to 1986, little official concern existed about nitrate pollution, although it was known that nitrate levels were rising in a number of water sources. Introduction of the EC 50 mg/litre standard in 1986 marked the beginning of the second phase. Although the standard was initially opposed by the U.K., an approach to meeting the standard was developed which relied heavily on water treatment options. Little attention was given to preventative measures, although advice was available to farmers on good agricultural practices through MAFF. The third phase began in 1989 and is continuing at present. Although attention has turned towards the development of preventative measures during this phase, little consensus has emerged regarding what specific actions should be taken. Different views have surfaced among key interests due, in large part, to the uncertainty which surrounds the nitrate issue. While MAFF has favoured a cautious experimental approach, the NRA is pressing for immediate restrictions in affected areas. The EC has attempted to initiate action among Member States to prevent nitrate pollution. There is considerable opposition among agriculturalists to the EC approach because it imposes severe restrictions on farmers while the effects of the measures on nitrate levels in water sources are uncertain. It appears likely that the development of agricultural measures to prevent nitrate pollution will continue to be the source of controversy and conflict within the U.K. and EC in the future.

Organizational Culture

Organizational cultures and participant attitudes often influence the ways in which institutions respond to particular water resource problems or issues. To clarify this point, organizational culture is defined here as "the norms (specific and tacit), and the values (general and explicit) which officials bring to decision-making and policy-making" (Wilks, 1987, 27).

One aspect of organizational culture significant for nitrate pollution is the close relationships among MAFF and lobby groups such as the National Farmers Union (N.F.U.) and the Country Landowners Association (C.L.A.). The influence of the N.F.U. on agricultural policy is considerable, and it has been suggested that the N.F.U. plays a joint role with government in the political management of the agricultural sector (Lowe *et al.*, 1986). A somewhat different view of the relationship is provided by the Parliamentary Director of the N.F.U., who has stated "we cannot pull any levers anywhere. What we can do is persuade people who have got access to the levers to operate them in directions we think will be beneficial" (Holbeche, 1986, 40).

Although the precise extent of the farming lobby's influence is difficult to determine, it is clear that it does have considerable access to government policy arenas and enjoys a close working relationship with MAFF. The limited extent of preventative measures which have been introduced to date to deal with nitrate pollution can be explained, at least in part, as one consequence of this close relationship.

A second important cultural factor is the attitudes of farmers and farming groups towards programs which are designed to reduce nitrate leaching losses. MAFF's Nitrate Sensitive Areas Scheme is currently the only programme in effect in the U.K. Farmers within the NSAs may join a Basic Scheme which places limitations on the use of nitrogen fertilizers and the ploughing of grassland. Alternatively, farmers may enter a Premium Scheme which requires arable land to be converted to alternative uses. The Scheme was initially opposed by many farmers on the grounds that it would reduce the value of agricultural land and that compensation payments to farmers were inadequate. After some adjustments in the scale of payments, the final uptake of the Basic Scheme was high (87.3% of the agricultural land within the designated NSAs). However, uptake of the Premium Scheme was low, at only 14.2% (Table 11.1). The difference in uptake figures can be attributed to the fact that the Premium Scheme requires fundamental changes away from arable production. While many farmers were willing to change land management practices under the Basic Scheme, few were willing to take the more radical steps required under the Premium Scheme.

Organizational cultures and participant attitudes have influenced institutional responses to the problem of nitrate pollution in the U.K. Farm lobby groups have considerable influence over MAFF, which remains largely in control of measures to prevent nitrate pollution at source despite the involvement of the DoE and NRA. Further, there has been considerable resistance on the part of farmers to measures designed to prevent nitrate pollution through fundamental changes in agricultural land use.

THE SIGNIFICANCE OF UNCERTAINTY AND CONFLICT

The development of institutional responses to nitrate pollution in the U.K. is characterized by considerable uncertainty and conflict. Specifically:

(1) The public health and environmental risks posed by nitrates in water are uncertain. This has led to conflicts over the setting of 'safe' limits for nitrate in drinking water.

(2) The precise causes of rising nitrate levels are uncertain, particularly in the case of groundwater. Different views of the causes exist among water and agricultural experts. As a result, little consensus exists regarding the development of policies to prevent nitrate pollution.

(3) The overlap in the policy responsibilities of the DoE and MAFF have led to conflicting approaches to the nitrate problem.

(4) MAFF has primary control of the agricultural sector and advocates more research prior to the implementation of preventative measures. This is reflected in the Nitrate Sensitive Areas (NSAs) Scheme.

(5) The influence of the farming lobby over government agricultural policy is considerable. This influence is reflected in the limited implementation of measures to prevent nitrate pollution from agricultural sources.

(6) It is likely that EC initiatives to prevent nitrate pollution will continue to cause conflict. The EC approach is based primarily on the restriction of fertilizer use, and the effects of such measures on nitrate levels in water are uncertain.

Under existing institutional arrangements, it is likely that the nitrate issue will continue to cause conflict among government, water management and agricultural interests. Although there is some degree of cooperation among these interests at present, a more coordinated approach is needed. In order to cope with the inevitable uncertainties of nitrate pollution, a coordinated approach must be based on institutional arrangements which encourage negotiation, consensus building and compromise. These institutional aspects of the nitrate issue in the U.K. are the focus of ongoing research by the author. It is anticipated that the research will lead to recommendations for the resolution of the nitrate conflict, and will offer insights for the integration of agriculture and water resources management.

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Monitoring, Analysis and Modelling

CHAPTER 12

THE ROLE OF MODERATE FLOW EVENTS AND BANK STRUCTURE IN THE DETERMINATION OF CHANNEL RESPONSE TO URBANIZATION

Craig R. MacRae and A. Charles Rowney

INTRODUCTION

Osterkamp (1980) identified the "controlling" and "modifying" factors which determine channel cross-sectional form. These factors could be generalized into upland and instream groups. The upland factors consist of the parameters describing the hydrologic and sediment regimes tributary to the stream channel, and the instream factors characterize the erodability and transportability of the boundary materials. However, translation of this conceptual understanding into a feasible and practical procedure for the design of Stormwater Management (SWM) ponds for instream erosion control represents a considerable challenge.

Wolman (1967) concluded that the process of urbanization constitutes a major disruption of the prevailing upland hydrologic and sediment regimes within a watershed. The effect of land use alteration on the flow regime may be generalized as a change in the natural storage of a catchment (McCuen, 1979). This alteration may result in an increase in both runoff volume and peak flow rate. The associated increase in flood frequency has been shown to be non-uniform with the increase diminishing with return period (Hollis, 1975; Figure 12.1).

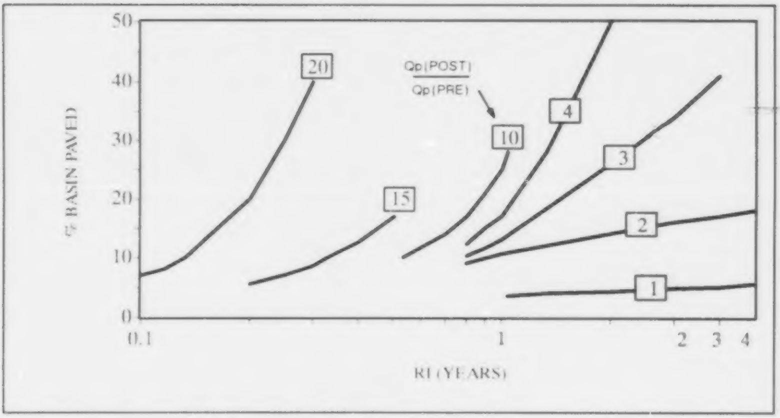

FIGURE 12.1. Effects of urbanization on flood peaks

The alteration of the sediment regime is somewhat more complex. Wolman offered the following scenario:

(1) construction results in aggradation leading to a choking of the stream channel; and,

(2) following development flows increase in rate and volume while sediment loads actually decrease as the surface becomes more impervious and the remaining denuded areas are stabilized with vegetation.

In Wolman's first stage, aggradation may destabilize the active channel leading to a new ultimate channel form characterized by "sedimentation patterns" (Brotherton, 1979). In the second stage, Morisawa and LaFlure (1979) hypothesized that the increase in direct runoff from the urbanizing upland area results in an increase in stream competence. This increase in competence manifests itself through channel enlargement by widening, deepening or both as governed by local bed-bank characteristics (Brotherton, 1979; MacRae, 1991). Indeed, process-form interpretations (Wolman, 1959; Leopold *et al.*, 1964; Simons and Li, 1982; Hooke, 1979; Harvey and Watson, 1986) have shown that dislodgement of boundary material by the shearing action of the sediment and water mixture is the dominant bed erosion process and responsible for the initiation of bank failure by mass movement due to basal scour (Thorne and Lewin, 1982; Yu and Wolman, 1986; Richards and Lorriman, 1987).

Although there are case studies to the contrary (Hollis and Luckett, 1976; Leopold, 1973), most have demonstrated the potentially adverse effects of uncontrolled urban stormwater runoff on stream channel form (Savini and Krammerer, 1961; Keller, 1962; Guy and Ferguson, 1962; Hammer, 1972; Gregory and Walling, 1973; Mansue and Anderson, 1974; Graf, 1975; Lazar, 1978; Allen and Narramore, 1985; Lee and Ham, 1988; Urbonas, 1980; 1988). The concepts of detention and retention storage were introduced in the form of stormwater management (SWM) measures to mitigate impacts associated with the alteration of the hydrologic regime. This was achieved through the reduction of flow rates by storage routing effects. Consequently, storage controls in the form of SWM ponds are central to most SWM policies.

Excessive sediment loadings resulting in aggradation of the channel have been addressed through the development of guidelines on sediment and erosion control for construction sites (Ontario, 1987). Beyond these guidelines, the morphological significance of the difference between the pre- and post-construction sediment regimes has not been addressed.

In Canada, millions of dollars have been spent and thousands of stormwater management ponds have been built, designed principally using the hydrologic approach, to control instream erosion. While the incorporation of instream erosion control measures into SWM policy, objectives and criteria represent a significant step forward, these measures have met with limited success and in some cases, have resulted in the aggravation of instream erosion (Lee and Ham, 1988; Bishop and Mather, 1990).

In this paper, the transverse distribution of sediment transport potential was computed for pre- and post-development flow series to evaluate the significance of flow events of different stages. Data on bankfull channel width, bank structure, and boundary material resistance to scour are used to suggest that bank structure may be an important determinate of channel response to alteration of the upland sediment and hydrologic regimes. Implications on design criteria are drawn leading to the development of an alternative design approach.

CURRENT POND DESIGN CRITERIA

There are two methods used for the design of storage facilities for the control of instream erosion hazard: the hydrologic, and the sediment continuity approaches. The hydrologic approach, referred to as the 'Zero Runoff Increase' (ZRI) method, is used most commonly. It is based on Leopold's (1968) observation that an increase in the magnitude and frequency of the flow of bankfull recurrence interval (1:1.5 to 1:2 years) was sufficient to cause the active stream channel to enlarge (Figure 12.2a). To offset this increase in scour potential peak flow, shaving techniques were proposed to reduce the post-development 1:2 year flow rate to the pre-development condition (Figure 12.2b).

Such a criterion means that the post- and pre-development flood frequency curves only intersect at one point, the 1:2 year (bankfull) recurrence interval (Kamedulski and McCuen, 1979). For all other frequencies, the effect of storage control on peak flow diminishes as the recurrence interval departs from the 1:2 year level. This characteristic has prompted the use of more complex outlet structures that actually reproduce the pre-development flood frequency curve following development for frequencies of up to the 1:100 year.

Such facilities, however, do little to reduce the increase in direct runoff volume (Lorant, 1988), or the frequency at which these events occur (James and Robinson, 1987; MacRae, 1991). Further, McCuen (1979) demonstrated that the increased duration of the controlled flows actually increased sediment transport potential and hence scour potential by several fold. Similar concerns were reported by Lorant (1983; 1988), and Bishop and Mather (1990).

Whipple *et al.* (1981) noted that it is not possible to modify post-development flows to reproduce the pre-development hydrologic regime in all aspects. They concluded that provision must be made so that the aggregate erosional effect of a series of storm events will not be greater than that prescribed to a known stable state. They rationalized that this may be achieved through provision of additional detention storage in excess of that required for ZRI control (Figure 12.2c). This concept is referred to as 'zero aggregate sediment transport increase' (ZASTI) in this paper. Its application was demonstrated using a one-dimensional, discrete event

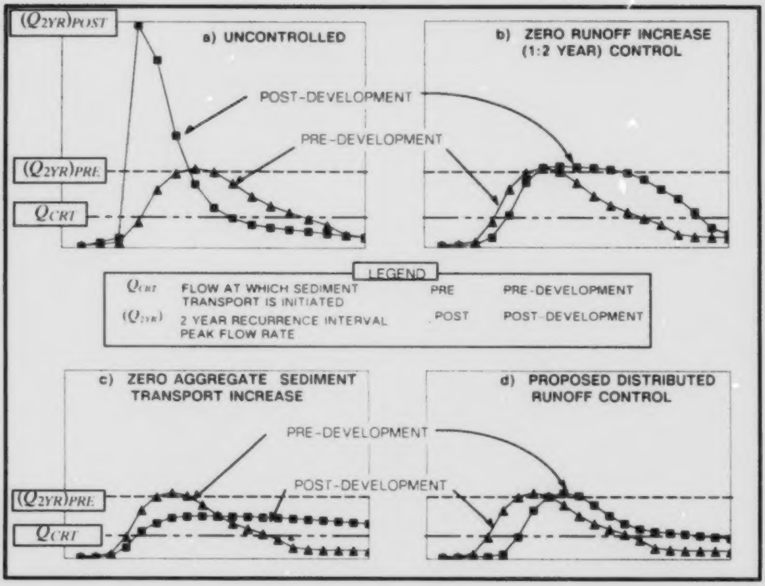

FIGURE 12.2. Comparison of pre- and post-development 1:2 year hydrographs for selected control methods

analysis of bed load sediment transport capacity by McCuen and Moglen (1988).

A variation of the hydrologic approach has been jointly proposed by the Ontario Ministries of the Environment and Natural Resources. This alternative approach requires that storage facilities for erosion control be sized to retain the surface runoff generated from a 25 mm precipitation event, and that this volume should be released over a minimum period of 24 hours (for areas of over 20 hectares). It differs from the ZRI method in that storage volumes and the time of retention are up to two times greater, and consequently, it is referred to as 'over control' (OC) in this paper.

The outflow hydrograph using the OC procedure resembles that derived using the ZASTI method. They differ in that the degree of storage control using the OC method is constant, applied uniformly to all watersheds regardless of the variation in factors affecting runoff generation or the resistance of the boundary materials to scour. Degree of control applied using the ZASTI approach varies with the average erodability of the boundary materials.

The principal concern with the ZRI and OC approaches is the exclusion of boundary material characteristics in the estimation of scour potential. The ZASTI method addresses this concern through the incorporation of critical velocity concepts as a measure of boundary material resistance to scour. However, all of these approaches are one-dimensional, and adopt an average measure of material erodability based on average hydraulic parameters for any cross-section. Natural channels, however, tend to be heterogeneous in structure and material composition such that boundary material resistance to scour varies in both the transverse and longitudinal directions. Similarly, the forces tending to dislodge and transport particles also vary in the transverse and longitudinal sense. The resulting variation in scour potential requires a two-dimensional modelling of the flow field at each cross-section. For example, consider the difference in scour potential for a channel formed in an intact firm clay material with a sand layer located at the bank toe in comparison to the same channel with the sand layer located near the top of bank. The difference in erosion potential between these two channel forms differs significantly yet such variations would not necessarily be recognized in a one-dimensional approach. Given such heterogeneities, a one-dimensional approximation of the channel system may not adequately describe scour potential.

A second concern is that current design methods use a design storm approach typically based on the channel forming significance of the 1:2 year design event. This assumption is based on work by Leopold *et al.* (1964), who deduced from observations of dissolved and suspended sediment loads, that "in many drainage basins a large proportion of the work is performed by relatively frequent events of moderate magnitude". To the extent that excess shear,

$$\tau_{EXT} = (\tau_o - \tau_{CRT}) \qquad [1]$$

in which, τ_{EXC} = excess boundary shear stress (Pa),

τ_o = instantaneous boundary shear stress (Pa), and
τ_{CRT} = critical boundary shear stress (Pa)

represents the rate of sediment transport, and assuming a log-normal frequency distribution of such stresses, they then observed that the product of the weight of material moved times the frequency will achieve a maximum value (Figure 12.3). This is referred to as Leopold *et al.*'s (1964) effective work curve. They observed that the maximum value corresponded to a recurrence interval (RI) from 1:1.5 to 1:2 years. They concluded that these flows were principally responsible for the hydraulic geometry of the active channel.

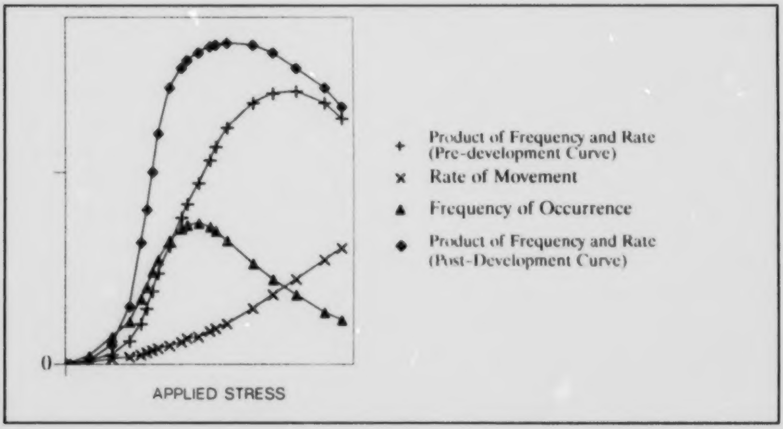

FIGURE 12.3 Probable alteration of Leopold *et al.*'s (1964) effective work curve

The non-uniform increase in flood frequency may result in an increase in the channel forming importance of moderate (1:0.5 to 1:1.5 year) or sub-bankfull flows (MacRae and Rowney, 1992). Leopold *et al.*'s (1964) effective work curve was developed from observations of non-urban streams and an increase in sediment transport potential for moderate flow events following urbanization may result in a shift in the effective work curve (Figure 12.3). Consequently, design criteria which do not account for the non-uniform increase in flow frequency may under-control moderate flow events and hence, under-control scour potential.

THE EFFECT OF URBANIZATION ON CHANNEL FORMING FLOWS

The cumulative sediment transport rate (q_S), at any point "P" about a channel perimeter through the course of a flow event (Figure 12.4) is defined using the general form of Meyer-Peter Muller relation (Shen, 1971) as,

$$(q_S)_P = \int_0^T m(\tau_o - \tau_{CRT})^b \, dt \qquad [2]$$

where,	τ_o	=	the instantaneous boundary shear stress at point "P",
	τ_{CRT}	=	the critical shear stress at point "P",
	b	=	an empirically derived exponent,
	m	=	an empirically derived coefficient, and
	T	=	event duration for which $q_S > 0$.

To determine the significance of the sediment transport potential associated with the number of flow events that reach a particular depth of flow, the channel was divided into a number of depth increments such that,

$$\Delta y = \left(\frac{y_{BFL}}{N}\right) \qquad [3]$$

where, y_{BFL} = bankfull channel depth, and
N = the number of depth increments.

The depth increments were numbered consecutively from 1 to N,

$$(j-1)\Delta y < (y_{INCR})_j \le j(\Delta y) \qquad [4]$$

in which, j = 1 to N.

A flow event at peak flow rate would achieve a maximum flow depth of y_{MAX} according to a stage-discharge function. The sediment transport potential for any flow event may then be mapped to a corresponding depth increment (Figure 12.4b).

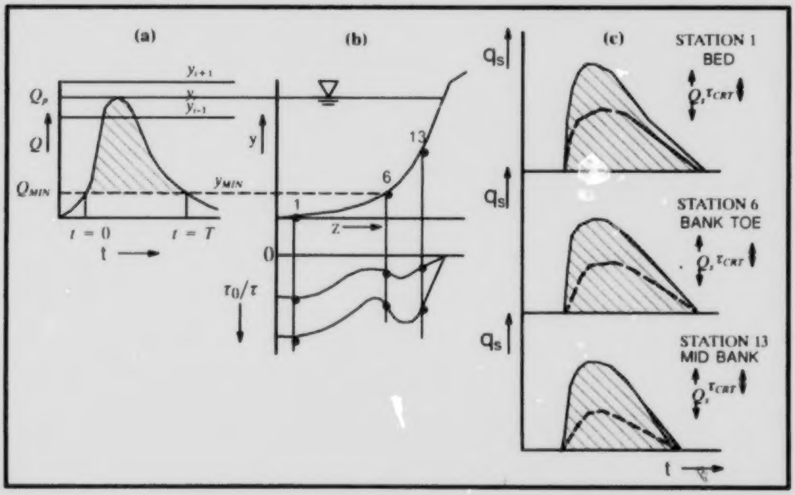

FIGURE 12.4. Definition sketch for determination of aggregate sediment transport potential for a flow event (a) hydrograph; (b) channel semi-perimeter and dimensionless boundary shear stress; (c) sediment transport potential

To examine the affect of the non-uniform increase in flood frequency on channel forming events, eqn. [2] was applied to a channel section formed in cohesive materials for a stream in the Ottawa vicinity. Flow, geodetic and geotechnical information were available for this site (MacRae, 1991). The channel configuration was representative of stable conditions as determined from an interpretation of fluvial forms and apparent activity rates. The bank material was composed of a firm, intact silty clay and the bed was composed of a very firm, intact clay characterized as relatively homogeneous, fine grained and cohesive.

A continuous hydrologic simulation model (QUALHYMO, Rowney and MacRae, 1991a) was used to generate pre- and post-development flow series using existing and future land use maps for a thirteen year period starting in January 01, 1971 and ending on December 31, 1983. Model parameters for the post-development state were derived from calibration studies on three urban watersheds in the Ottawa area (Rowney and MacRae, 1991b).

Three boundary stations were selected for analysis; the mid bank (Station 13), the bank toe (Station 8), and the mid channel bed (Station 1). Boundary shear stress at these stations was determined for selected depths using a two-dimensional boundary shear stress model (MacRae, 1991). Cumulative aggregate sediment transport potential (W_y), was then determined at the three stations by summing eqn. [2] for each event then aggregating $(q_s)_P$ by increment of depth.

In this case, an event was defined as any set of contiguous time increments wherein excess boundary shear stress is greater than zero. The total number of such events (NEVENT) increased from 824 to approximately 2000 (at Station 1) following two-thirds development of the basin under predominantly residential land use. The distributions of NEVENT by depth are illustrated in Figure 12.5 (a) to (c) for Stations 1, 8, and 13 respectively. The majority of the increase in the number of events is recorded for depths of $y \leq \frac{1}{2} y_{BFL}$ at Stations 1 and 8 (Table 12.1). Over 80 percent of the increase in number of events occurs by $y \leq \frac{3}{4} y_{BFL}$ for the same two stations. The lower value for Station 13 reflects the lower depth and duration of inundation, lower flow velocities, and hence lower boundary shear forces acting on this station.

TABLE 12.1
Percent Increase In NEVENT For Selected Depths

Depth	Station Number		
y (m)	1 (%)	8 (%)	13 (%)
$\frac{1}{2} y_{BFL}$	74	62	19
$\frac{2}{3} y_{BFL}$	85	70	56
$\frac{3}{4} y_{BFL}$	86	84	67
y_{BFL}	96	95	90

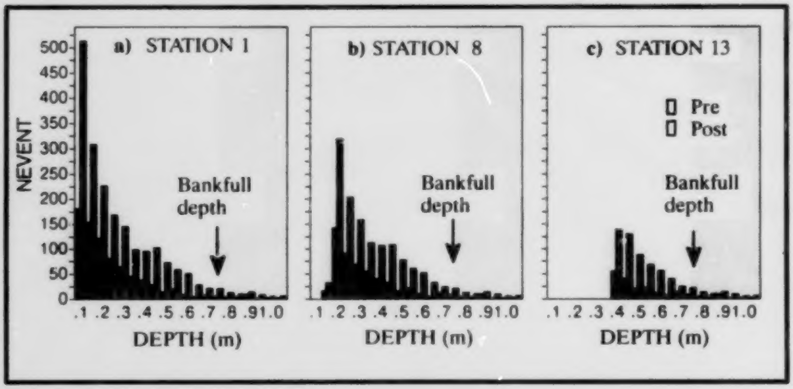

FIGURE 12.5. Number of flow events by increment of depth under pre- and post-development land use scenarios

Figure 12.6 (a) to (c) compares the distribution of W_y for pre- and post-development conditions. The distribution of $(W_y)_{PRE}$ tends to support the channel forming dominance of bankfull flows at Station 13, however, scour potential is approximately an order of magnitude lower at this station relative to Stations 1 and 8. The later stations illustrate the significance of

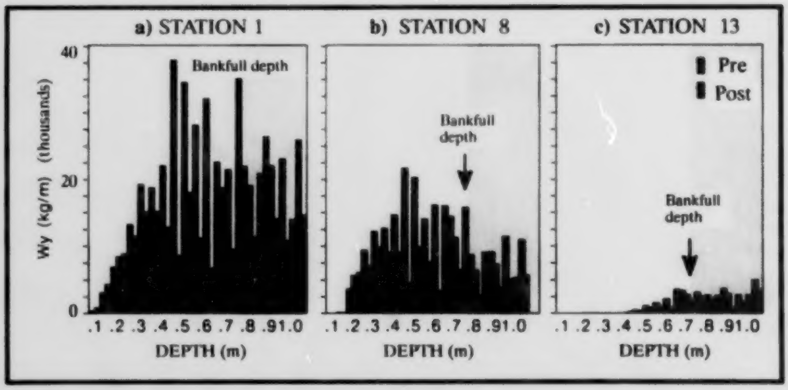

FIGURE 12.6. Cumulative aggregate sediment transport potential by increment of depth

the entire range of flows in determining channel form. However, the post-development distribution of $(W_y)_n$ demonstrates the increased significance of flow events in the moderate flow range. The maximum increase occurred between $0.5y_{BFL} \leq y \leq 0.73y_{BFL}$ for Stations 1 and 8, and $0.66y_{BFL} \leq y \leq 0.8y_{BFL}$ for Station 13. This represents an increase in scour potential in the order of 2 to 4 times for flows in the moderate event range over pre-development conditions.

The distribution of the difference in cumulative aggregate sediment transport potential is illustrated in Figure 12.7 (a) to (c). The greatest difference in (W_y) occurs at depths of $0.5y_{BFL} \leq y \leq 0.66y_{BFL}$ for Stations 1 and 8, and at approximately $y = 0.85y_{BFL}$ at Station 13. For this case, over 67, 60 and 31 percent of the increase in scour potential occurred by $y = .75y_{BFL}$ at Stations 1, 8 and 13 respectively (Table 12.2). Noting that scour potential at Station 13 is approximately an order of magnitude lower than that reported at Stations 1 and 8, this figure shows that the majority of the total increase in cumulative aggregate sediment transport occurs for moderate flow depths. This supports the hypothesis that Leopold *et al.*'s (1964) effective work curve increases in magnitude and that the maximum shifts towards less frequent moderate flow events. Consequently, these events may become the dominant channel forming flows following urbanization.

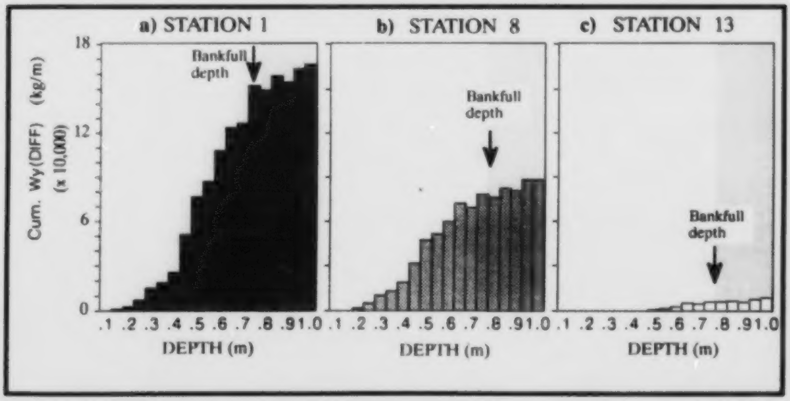

FIGURE 12.7. Cumulative change in cumulative aggregate sediment transport potential by increment of depth

TABLE 12.2
Summary of Cumulative Post- Minus Pre-Development Aggregate Sediment Transport Potential At Selected Boundary Stations (%)

STATION	$\Sigma[(W_y)_{POST} - (W_y)_{PRE}]$			
	$.5y_{BFL}$	$.66y_{BFL}$	$.75y_{BFL}$	$1.0y_{BFL}$
1	31	47	67	94
8	15	54	60	90
13	0	19	31	68

THE SIGNIFICANCE OF BANK STRUCTURE

The significance of the transverse variation in boundary materials was investigated through a field survey of seven streams in Surrey, British Columbia. These watersheds were developed under the auspices of the District of Surrey's "Natural Drainage Policy" (Lee and Ham, 1988). This policy includes the use of buffer strips and the implementation of a 1:5 year pond for the control of in-stream erosion hazard.

Stream sections were located downstream of the storage facilities. The survey of each section included a classification of material resistance to scour for each stratigraphic unit composing the bed and bank materials (MacRae, 1991). This was done using standard field techniques for the classification of material stickiness, plasticity and firmness (Buol *et al.*, 1973; Holtz and Kovacs, 1981), and verified with laboratory measurements of Plastic Index (PI), Liquid Limit (LL), and particle size distribution.

Stickiness, plasticity and firmness are separate qualitative measures of material consistence (Buol *et al.*, 1973). The independence of these parameters was examined through a cross-correlation analyses of twenty-eight observations. It was found that the variation in any one variable explained by any one of the other two variables is poor.

Since standard soil classification procedures require all three parameters to characterize the consistence of a material a model which incorporates all three parameters should be considered. The following relation is one of several possible alternatives tested,

$$W_R = m(SCORE) + b \qquad [5]$$

in which,

$$(SCORE) = (X1 + X2 + X3) \qquad [6]$$

where, SCORE = a composite measure of the resistance to scour
X1 = measure of wet consistence (stickiness),
X2 = measure of moist consistence (plasticity),
X3 = measure of dry consistence (firmness).

Sensitivity to scour is inversely proportional to material consistence as measured by plasticity and unconfined shear strength (ASCE, 1975) and hence to the value of SCORE.

SCORE values were computed from field classifications of bank toe stratigraphic units ($SCORE_{TOE}$). The bank toe stratigraphic units receiving the lowest SCORE for each section were then compared with W_R (Figure 12.8). The significance of bank structure was examined by comparing the least resistant bank toe stratigraphic unit in accordance with field classification of stickiness (X1), plasticity (X2), and firmness (X3) for the seven study reaches to the ratio of post- to pre-development bankfull channel width (W_R).

$$W_R = \frac{W_{POST}}{W_{PRE}} \qquad [7]$$

in which, W_{POST} = post-development bankfull channel width, and
W_{PRE} = pre-development bankfull channel width.

$SCORE_{TOE}$ recorded an r^2 value of 0.815 with a standard error in the regression coefficient of 21.8 percent using simple linear regression analysis (Figure 12.8). The use of SCORE, which is a composite of field classifications of wet, moist and dry consistence, as a measure of material resistance to scour was demonstrated by MacRae (1991). Accordingly, SCORE values may be used to compare the resistance of any bank stratigraphic unit or group of strata to scour. This was done by correlating SCORE for the least resistant mid bank stratigraphic unit and a composite of all stratigraphic units on the least resistant bank with W_R. These were determined as,

$$(SCORE)_{BNK} = (X1 + X2 + X3)_{BNK} \qquad [8]$$

and

$$(SCORE)_{CMP} = (X1 + X2 + X3)_{CMP} \qquad [9]$$

in which, BNK = a subscript referring to the mid bank stratigraphic unit, and
CMP = a subscript referring to a composite sample comprised of all bank stratigraphic units.

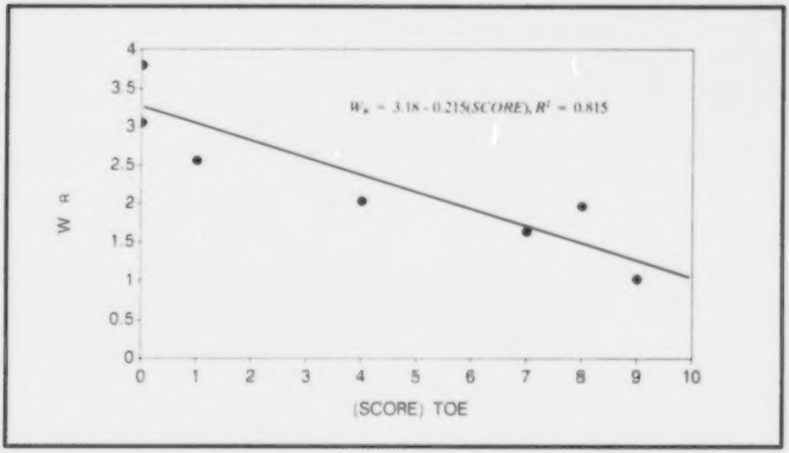

FIGURE 12.8. Correlation between Wr and the least resistant bank toe stratigraphic unit

The resulting correlation coefficients are compared to that obtained for $SCORE_{TOE}$ in Table 12.3. The relatively high correlation observed for $SCORE_{CMP}$ results from the overlap with bank toe stratigraphic units for unstratified banks (4 of the 7 cases). $SCORE_{CMP}$ for stratified banks was found to be a poor indicator of channel susceptibility to enlargement. Likewise the least resistant mid bank stratigraphic unit was found to be a poor indicator of the susceptibility of the channel to enlargement.

TABLE 12.3
Correlation Matrix Of W_R On SCORE Values For Least Resistant Bank Toe And Mid Bank Stratigraphic Units And Composite Bank Samples

SCORE	W_R (r^2)
TOE	.815
MID	.495
CMP	.743

It was noted that the greatest increase in scour potential was associated with moderate flow events of $y \leq .7\ y_{BNK}$ and consequently have less effect on mid-bank stratigraphic units but a large impact on boundary materials in the bank toe region. This finding is consistent with field observation of accelerated bank undercutting following urbanization and points to the relative importance of bank structure in the determination of channel form and response. The implication on design procedures for the control of instream erosion potential is the need to recognize the increased contribution of moderate flow events on channel form and distribute the degree of storage control in proportion to the increase in scour potential by stage. The later point incorporates the transverse variation in bank material characteristics and bank structure and consequently, requires a two-dimensional approximation of the channel and the flow field. The degree of storage control will vary within and between watersheds depending upon physiographic characteristics and the degree of alteration of flow geometry.

An example of the form of the output hydrograph from the control pond designed using a procedure based on these concepts (Distributed Runoff Control; MacRae, 1991), is illustrated in Figure 12.2d. This procedure was developed to minimize instream erosion potential about a channel perimeter, and it will be described in a subsequent paper.

CONCLUSIONS

The greatest increase in scour potential following urbanization may be associated with moderate flow events. The effect of this increase is to shift channel forming dominance away from bankfull flows toward sub-bankfull flows of recurrence intervals between 1:0.5 and 1:1.5 years. These events have a pronounced affect on the scour potential in the bank toe region. Correlations between the ratio of post- to pre-development bankfull channel width and the least resistant bank toe stratigraphic unit indicate that bank structure may be an important determinant in channel sensitivity to flow regime alteration.

Design methods for the control of instream erosion potential should minimize the difference in the transverse distribution and magnitude of scour potential between pre- and post-urban conditions. Such procedures should account for the non-uniform increase in the number of runoff events, heterogeneities in boundary material resistance to scour and bank structure. This would require a two-dimensional approximation of the flow field and boundary material resistance.

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CHAPTER 13

A KNOWLEDGE BASED EXPERT SYSTEM FOR SOIL AND WATER MANAGEMENT

H. Montas and C.A. Madramootoo

INTRODUCTION

Improving water quality and providing a sustainable basis for agriculture are important objectives of soil and water conservation programs. A key element is the selection of measures that reduce erosion from intensely cultivated fields. A typical soil conservation plan consists of changes in land use and/or crop management, and the installation of conservation structures. The selection of appropriate practices is based on factors such as land use, topography and soil types, as well as economic and social factors. Experienced soil conservation engineers are, however, scarce in Canada. Consequently, there is a need for computer-based tools that permit engineers and planners to assess land use, perform erosion analysis, and develop appropriate conservation plans with greater ease and reliability.

Decision Support Systems (DSS) show great promise for strategic planning of soil conservation efforts. This technology is used by managers and planners in the business sector to select appropriate development plans and perform strategic market analyses. A DSS can similarly aid in the selection of appropriate soil conservation practices for agricultural watersheds.

Expert Systems (ES), Geographical Information Systems (GIS) and detailed hydrology and erosion process models are additional tools that can be used to design water quality and non-point source pollution control programs. These tools can be integrated in the framework of a DSS and provide for synergistic capabilities (Heatwole *et al.*, 1987).

This paper describes a DSS for soil conservation planning and applies it to a small watershed in southwestern Quebec. The DSS integrates a GIS, a distributed parameter erosion model, and an expert system. It is applicable to watersheds of up to 20 km^2, and is focused on alleviating erosion by water.

DESCRIPTION OF THE DECISION SUPPORT SYSTEM

The soil conservation Decision Support System designed for this study, is represented in Figure 13.1. It consists of a GIS, the ANSWERS model, an ES and some interfaces. The components may be used separately, or in sequence, depending on the nature of the problem.

The Geographical Information System

The GIS was developed at McGill University (Montas, 1990). The software is written in QuickBASIC v4.5, and can be executed on an IBM or compatible microcomputer, operating under DOS with 640 kb of storage. An 80286 math coprocessor would be preferable, but not necessary. The GIS was designed specifically for hydrologic modelling and erosion assessment. It was decided to develop the GIS for the following reasons: (1) a relatively small land area was to be stored in the system; (2) the input data were obtained from maps and field surveys; (3) the data storage structure had to be perfectly understood so that interfaces may be easily developed; and (4) commercial systems, at the time, focused on geographical operations that were not directly useful to hydrologic modelling and erosion assessment.

Each study watershed is stored and retrieved separately from the GIS. This format is a natural organization for hydrologic data, since most

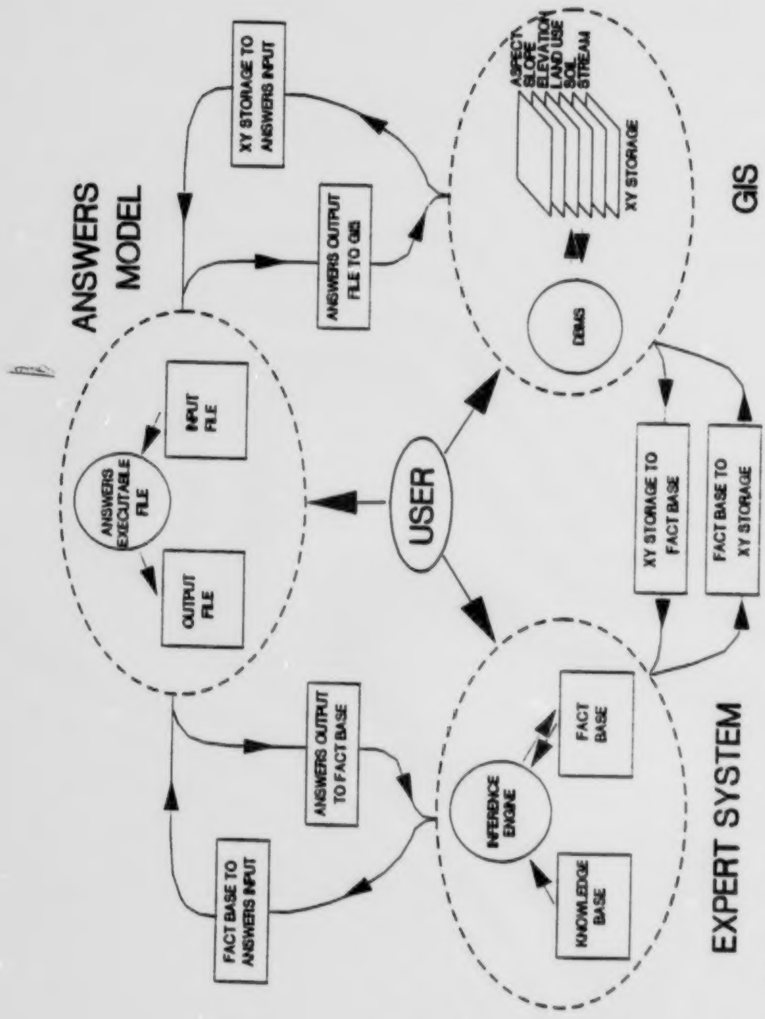
ANSWERS MODEL
INPUT FILE
ANSWERS EXECUTABLE FILE
OUTPUT FILE
XY STORAGE TO ANSWERS INPUT
ANSWERS OUTPUT FILE TO GIS
FACT BASE TO ANSWERS INPUT
ANSWERS OUTPUT TO FACT BASE
USER
DBMS
ASPECT
SLOPE
ELEVATION
LAND USE
SOIL
STREAM
XY STORAGE
GIS
XY STORAGE TO FACT BASE
FACT BASE TO XY STORAGE
INFERENCE ENGINE
FACT BASE
KNOWLEDGE BASE
EXPERT SYSTEM

FIGURE 13.1. Soil conservation decision support system (DSS)

analyses are watershed oriented. Six data layers are defined: stream, land use, soil, elevation, slope and aspect. A raster representation is used with a pixel size of one hectare. Raster was chosen over vector, because is lends itself naturally to finite difference modelling of hydrologic processes. The one hectare cell size was observed to accurately represent the spatial variability of land use of southwestern Quebec.

ANSWERS

ANSWERS is the acronym for Areal Nonpoint Source Watershed Environment Response Simulation. It is a distributed parameter, event-based, deterministic hydrology and erosion model (Beasley *et al.*, 1980). ANSWERS predicts runoff and sediment concentrations at the watershed outlet, as well as the spatial distribution of eroded and deposited sediments within the basin. It uses a finite difference solution for the infiltration and flow equations, which makes it well suited to linkage with a raster GIS. The model is written in Fortran, and can be executed on an IBM PC or compatible machine with 640 kb of storage.

The watershed is represented as a set of square cells which may be from 1 to 4 hectares in area. ANSWERS uses Holtan's infiltration equation to compute excess rainfall for each cell, and routes runoff from cell to cell using Manning's equation. Soil detachment is modeled using adaptations of the relationships of Meyer and Wischmeier (1969). Sediment transport is calculated by a piecewise continuous function of slop and discharge (Beasley and Huggins, 1982). ANSWERS version 4.840815 was used in this study.

Montas and Madramootoo (1991) evaluated the ANSWERS model, and found that predicted runoff and erosion in the Ottawa-St. Lawrence lowlands of western Quebec and eastern Ontario closely matched field observations. The model was tested on two small watersheds, with 24 rainfall-runoff events. Furthermore, Montas and Madramootoo (1991) developed a database of local input values for ANSWERS, and validated the model for local conditions. Confidence in use of the model as part of the DSS was, therefore, established.

The Expert System

A backward-chaining expert system written in Prolog was implemented. Prolog was chosen because of its close relationship to predicate calculus. This choice later simplified the translation of knowledge formalized in the latter language to an executable form. Turba Prolog v2.0 (Borland, 1988) was used as the language compiler. The expert system runs under DOS on an IBM PC or compatible machine with 640 kb of storage. An 80286 math coprocessor is necessary for program execution.

Soil conservation knowledge was formalized using the methodology outlined in Genesereth and Nilsson (1987). The selection of soil conservation practices was conceptualized by defining an applicable universe of discourse. This universe of discourse coincides with the problem-solving space of the DSS, and hence is a superset of the data stored in the GIS.

The objects forming the universe of discourse are watershed cells, land uses, soil types, slopes and land management practices. Cell objects consisted of an x-y coordinate pair and a cell identification number. Land use objects were corn, small grain, hay, pasture, vegetable, nursery, forest and lawn sod. Soil type objects were the local soil series. Slope objects were the number representing the slope and aspect of the terrain. Management practice objects were crop rotation, strip cropping, planned grazing, conservation tillage, deep tillage, contour farming, filter strip, grassed waterway and terrace. These practices are defined in USDA (1985).

Appropriate binary relations were defined to associate watershed cells with other objects. The crop type, soil type, slope and advised-practice relations were used to link crop, soil, slope and management practice objects with watershed cells.

Additional relations were defined to describe object properties. The unary relation 'rowcrop' was defined to classify land uses. Three unary relations were defined for soils: cohesive, impervious and sand-over-clay. A binary relation called topography was used to classify slopes into steep (> 5%), moderate (between 1 and 5%) and level (< 1%). This relation also identified depressions. The unary relation 'streamcell' identified watershed cells through which a stream passed.

Rules of soil conservation practice selection were obtained from various literature sources including Hurni (1988) and Troeh *et al.* (1980). Eleven soil conservation practice selection rules were defined. Appropriate conservation practices for various crop, soil and topographic conditions are depicted in Figure 13.2. The rules are applicable on a pixel basis.

FACTORS PRACTICE	ROWCROP	PASTURE	IMPERVIOUS SOIL	COHESIVE SOIL	SAND OVER CLAY	LEVEL LAND	FAIR SLOPE	STEEP SLOPE	DEPRESSION	ADJACENT TO STREAM
CONSERVATION TILLAGE	⊕					⊕				
DEEP TILLAGE					⊕	⊕				
OR			⊕			⊕				
CONTOUR FARMING	⊕			⊕			⊕			
CROP ROTATION	⊕			⊖		⊕				
PLANNED GRAZING				⊖				⊕		
OR		⊕								
STRIP CROPPING	⊕			⊖			⊕			
FILTER STRIP						⊕				⊕
GRASSED WATERWAY									⊕	
TERRACE				⊕				⊕		

FIGURE 13.2. Selection criteria for soil conservation practices

The Interfaces

Interfaces are used to transfer data from one component of the DSS to another. These programs were written to QuickBasic v4.5. An explanation of the function of each interface is best illustrated by simulating the use of the DSS.

Data representing a study watershed is initially entered and stored using the GIS. The XY STORAGE to ANSWERS INPUT interface (*cf.*

Figure 13.1) is then used to prepare an elemental data file for ANSWERS using the GIS data. The elemental data file is appended to a predata file that contains a description of the design rainfall and the physical properties of crops, soils, streams and groundwater in the basin. ANSWERS OUTPUT to XY STORAGE interface is used to transform the spatial distribution of erosion results in a format compatible with the GIS. The GIS may then be used to visualize and plot erosion in the study basin.

The XY STORAGE to FACT BASE interface is used to create a Prolog compatible database representing the data stored in the GIS. The ANSWERS OUTPUT to FACT BASE interface creates an additional Prolog database containing the spatially distributed erosion information resulting from the ANSWERS simulation. The expert system is run and produces a database containing the advised management practices for each cell with erosion above a chosen threshold. The FACT BASE to XY STORAGE interface is then used to transform this database into a format compatible with the GIS. The selected conservation practices may then be plotted.

The FACT BASE to ANSWERS INPUT interface is then used to incorporate the selected conservation practices in ANSWERS input file. ANSWERS is then run and the results are transferred to the GIS for plotting. The new spatial distribution of erosion can then be examined.

APPLICATION OF THE DSS TO SOUTHWESTERN QUEBEC

Study Region

The St-Dominique watershed is a small agricultural catchment representative of southwestern Quebec. The watershed is located approximately 50 km west of Montreal. The watershed boundary, river system, and outlet are shown in Figure 13.3. Land-use, soils, and topography of the watershed are shown in Figures 13.4 to 13.6 and Table 13.1. The area of the basin is 8.13 km^2 and the average slope is 0.39%. The predominant soil type is a sandy loam and the most cultivated crop is corn.

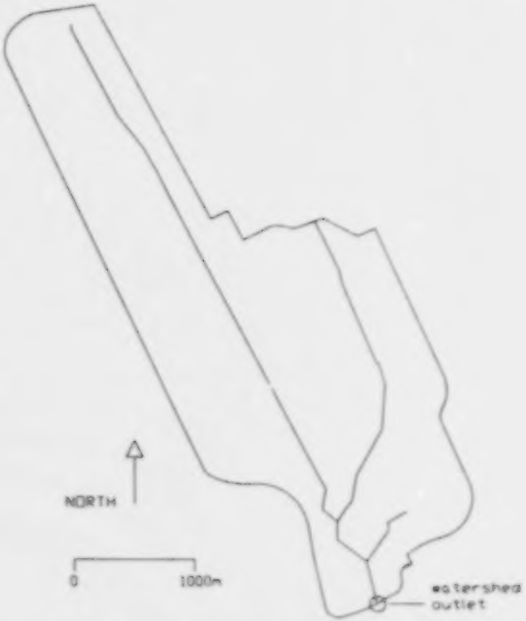
NORTH
0
1000m
watershed outlet

FIGURE 13.3. St-Dominique watershed boundary and river system: St-Dominique, Quebec

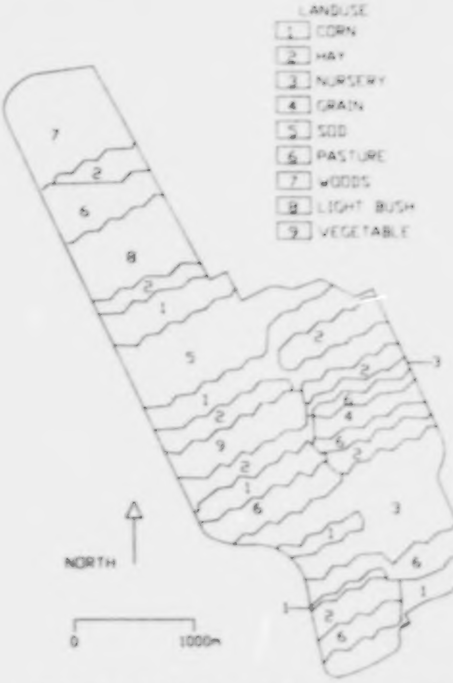
LANDUSE
1 CORN
2 HAY
3 NURSERY
4 GRAIN
5 SOD
6 PASTURE
7 WOODS
8 LIGHT BUSH
9 VEGETABLE
NORTH
0
1000m

FIGURE 13.4. Land use: St-Dominique watershed

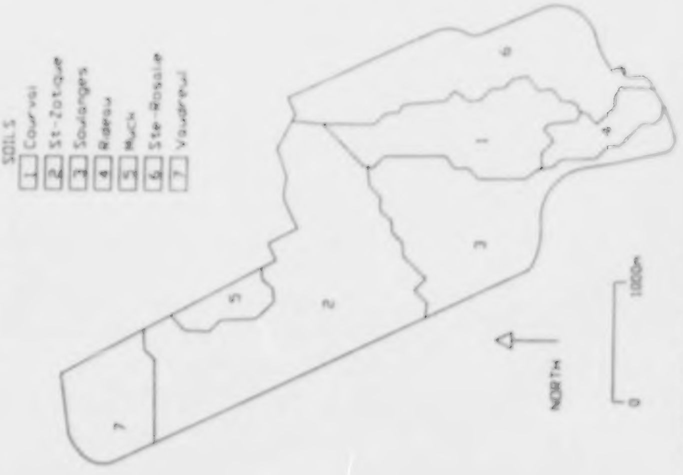
SOILS
1 Courval
2 St-Zotique
3 Soulanges
4 Rideau
5 Muck
6 Ste-Rosalie
7 Vaudreuil
1
2
3
4
5
6
7
NORTH
0
1000m

FIGURE 13.5. Soils: St-Dominique watershed

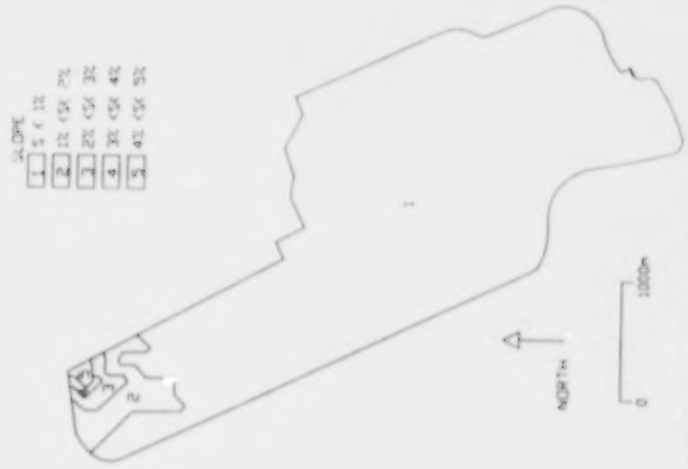
SLOPE
1 S < 1%
2 1% <S< 2%
3 2% <S< 3%
4 3% <S< 4%
5 4% <S< 5%
1
2
3
4
5
NORTH
0
1000m

FIGURE 13.6. Slope: St-Dominique watershed

TABLE 13.1
Composite Analysis of the Land Use, Soil Types and Slopes of the St-Dominique Basin

Percentage of the Land Use, Soil Type and Slope Combination in the Basin

		Soil Type:							
LAND USE	SLOPE(%)	Ro	R	Cy	Za	S	V	M	TOTAL
CORN	< 1	4.0	1.4	2.2	9.7	4.3	--	--	21.6
HAY	< 1	3.9	0.7	2.0	4.3	5.6	0.2	0.1	17.1
	1 to 2	--	--	--	0.3	--	--	--	
PASTURE	< 1	3.5	1.2	2.5	3.4	3.2	--	0.5	14.5
	1 to 2	--	--	--	0.1	--	--	0.1	
TREE NURSERY	< 1	6.6	0.7	5.1	--	1.7	--	--	14.1
SOD FARM	< 1	--	--	--	10.0	--	--	--	10.0
WOODS	< 1	--	--	--	0.7	--	2.6	--	9.8
	1 to 2	--	--	--	0.2	--	4.3	--	
	> 2	--	--	--	--	--	1.9	--	
BUSH	< 1	--	--	--	4.5	--	--	2.5	7.1
	1 to 2	--	--	--	--	--	--	0.1	
VEGETABLE	< 1	--	--	--	--	3.7	--	--	3.7
GRAIN	< 1	1.0	--	1.2	--	--	--	--	2.1
	TOTAL:	19.0	4.0	13.0	33.2	18.5	9.09	3.3	100.0

Ro - Ste-Rosailie clay
R - Rideau clay
Cv - Courval sandy loam
Za - St-Zotique sandy loam
S - Soulanges very fine sandy loam
V - Vaudreuil loamy fine sand
M - Muck well decomposed organic matter

Procedure

The Decision Support System was used to generate a soil conservation plan for the St-Dominique watershed. The objective was a 50% reduction in sediment yield and average cell erosion. Such a target is generally chosen for soil conservation planning purposes on watersheds with mixed land-use, where less than 50% of the land area is under intensive agriculture.

Erosion 'hot spots' were targeted using an observed rainfall event with a return period of 25 years. This event occurred on July 19, 1989 in Harrow, Ontario (Table 13.2). The storm lasted for 51 hours and generated

TABLE 13.2
Hyetograph for the Design Storm of Harrow Ontario, July 1989

DATE	TIME	PRECIPITATION (mm)
July 19, 1989	12:00 - 01:00	1
	01:00 - 02:00	3
	02:00 - 03:00	1
	03:00 - 07:00	0
	07:00 - 08:00	10
	08:00 - 09:00	7
	09:00 - 10:00	11
	10:00 - 11:00	1
	11:00 - 12:00	35
July 20, 1989	00:00 - 01:00	17
	01:00 - 02:00	25
	02:00 - 03:00	43
	03:00 - 04:00	6
	04:00 - 05:00	3
	05:00 - 06:00	1
	06:00 - 07:00	0
	07:00 - 08:00	5
	08:00 - 09:00	40
	10:00 - 11:00	9
	12:00 - 13:00	18
	13:00 - 14:00	10
	14:00 - 15:00	1
	15:00 - 16:00	0
	TOTAL	247 mm

247 mm of rainfall. The peak one hour rainfall intensity was 43 mm/h. A once-in-25 year design storm is generally used for hydrologic design purposes on small agricultural watersheds, to plan irrigation, drainage and soil conservation systems. The storm for Harrow was chosen because it

represents actual conditions, and detailed rainfall intensity data were available. Although Harrow is some 800 km west of the study area, similar rainfalls are not uncommon in the summer months.

Erosion 'hot spots' were defined as cells with more than 1 t/ha of soil lost due to this event. This value of 1 t/ha is lower than the maximum permissable erosion rate of 4.5 t/ha for renewable soils (Hall *et al.*, 1985). The value of 1 t/ha serves as a safety factor in the design of the soil conservation plan.

All applicable erosion control practices were determined by the expert system. The system selected more than one applicable practice for each cell. A single practice was then selected based on farmer preferences and spatial homogeneity criteria. The only exception was for cells adjacent to a stream, in which case a filter strip could also be selected in addition to another practice.

The effect of the selected conservation practices was assessed using ANSWERS. Conservation tillage was modeled by increasing the steady-state infiltration rate and maximum infiltration rate of the soils by 25%, and by increasing the surface roughness by 20% as suggested in the ANSWERS manual (Beasley and Huggins, 1981). The effect of surface residues was reflected in the USLE C parameter. Deep tillage was modeled as a 50% increase in the infiltration rate parameters. Contour farming was assumed to reduce the USLE P factor to 0.55. Crop rotation and planned grazing were modeled by decreasing the USLE C parameter. Filter strips were assumed to be 25 m in width.

Results

The predicted response of the St-Dominique watershed to the design storm is presented in Table 13.3. The predicted sediment yield was 314 tonnes and the total amount of eroded soil was 542 tonnes. This erosion took place in 300 of the 868 basin cells. The average soil loss for these cells was 1.8 tonnes.

The spatial distribution of erosion within the basin is presented in Figure 13.7. Most of the erosive cells were located in the southern half of

TABLE 13.3
Response of the St-Dominique Watershed to the Design Storm

Total Erosion	542.1	tonnes
Maximum Erosion Rate	8.956	t/ha
Average Erosion Rate	1.807	t/ha
Total Sediment Yield	313.7	tonnes
Maximum Concentration of Suspended Sediments	3.686	g/l

the basin. This was due in part to the lower infiltration rates which caused surface runoff and erosion. A large amount of erosion came from a band 700 m wide which runs from east to west. This band corresponds to a tree nursery. The soils in this region have a relatively coarse texture but are compacted and hence have low infiltration rates. The combination of bare conditions, high erodibility and low infiltration rates caused the erosion. Table 13.4 summarizes the soil loss in the St-Dominique basin for various soil type-land use combinations.

TABLE 13.4
Total Erosion in Tonnes for Soil Type-Land Use Combinations in St-Dominique

	SOIL TYPE				
LAND USE	Cv	Ro	S	Za	TOTAL
CORN	27.174	46.708	43.280	0.151	117.313
GRAIN	0.927	7.578	–	–	8.505
HAY	1.731	0.488	2.973	–	5.192
PASTURE	8.605	7.949	19.094	–	35.648
TREE NURSERY	135.402	168.794	46.721	–	350.917
VEGETABLE	–	–	24.501	–	24.501
TOTAL	173.839	231.517	136.569	0.151	542.076

Fifty-one percent of the eroded cells lost more than 1 tonne of soil. These cells occupied an area of 1.5 km^2 or 17.6% of the basin surface. They,

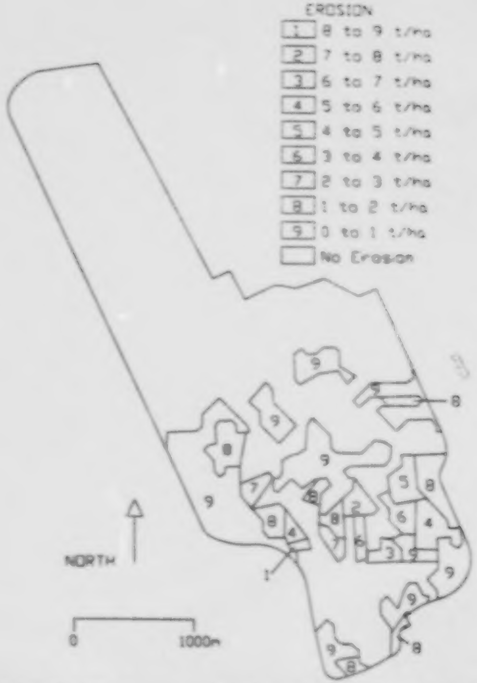
EROSION
1 8 to 9 t/ha
2 7 to 8 t/ha
3 6 to 7 t/ha
4 5 to 6 t/ha
5 4 to 5 t/ha
6 3 to 4 t/ha
7 2 to 3 t/ha
8 1 to 2 t/ha
9 0 to 1 t/ha
No Erosion
NORTH
0
1000m

FIGURE 13.7. Sources of erosion: St-Dominique watershed

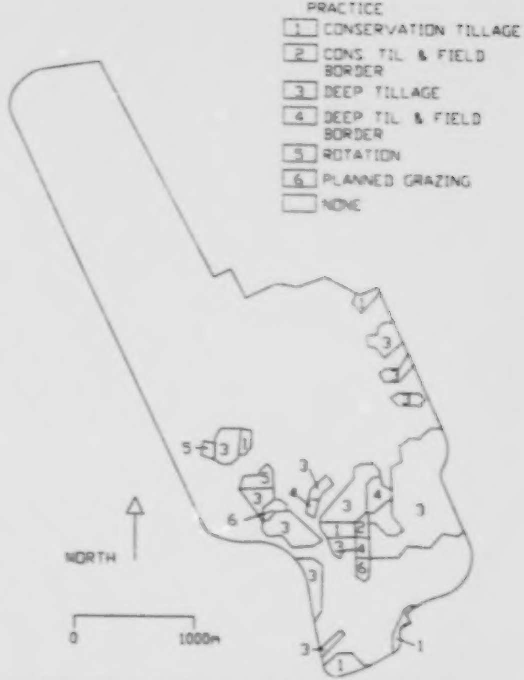
PRACTICE
1 CONSERVATION TILLAGE
2 CONS. TIL & FIELD BORDER
3 DEEP TILLAGE
4 DEEP TIL & FIELD BORDER
5 ROTATION
6 PLANNED GRAZING
NONE
NORTH
0
1000m

FIGURE 13.8. Soil conservation practices selected by expert system: St-Dominique watershed

however, contributed 88% to the total erosion of the basin. This shows that by reducing the soil loss in a small, well targeted portion of an agricultural watershed, total erosion can be substantially reduced.

The conservation practices selected by the expert system are presented in Figure 13.8. The Expert System chose conservation tillage for 23 cells, deep tillage for 115 cells, corn/hay crop rotation for 12 cells and planned grazing for 4 cells. Filter strips were identified for 9 cells. The reasons for the predominance of deep tillage in this watershed were that most soils consist of shallow layers of sandy loam over clay subsoil and that the tree nursery was the most eroded section. The owner of the tree nursery had expressed an interest in deep tillage which was taken into account in the decision process.

The effect of the conservation practices on the response of the St-Dominique watershed to the design storm is shown in Table 13.5. The sediment yield was 153 tonnes and the total erosion was 267 tonnes. The average erosion rate for eroded cells was 0.881 t/ha. The reductions were 50.7% and 51.2% for sediment yield, and average cell erosion rate, respectively. The target reduction of 50% in both sediment yield and average erosion rate was, therefore, achieved.

TABLE 13.5

Effect of Soil Conservation Practices on Erosion at St-Dominique

Total Erosion	267.1	tonnes
Maximum Erosion Rate	5.994	t/ha
Average Erosion Rate	0.881	tonnes
Maximum Concentration	2.372	g/l

The selected soil conservation practices lowered the number of highly erodible cells substantially. Figure 13.9 presents the spatial distribution of erosion when the conservation practices are implemented. There were only two cells with more than 5 t/ha of erosion. Most of the eroded cells (71%) had rates below 1 t/ha.

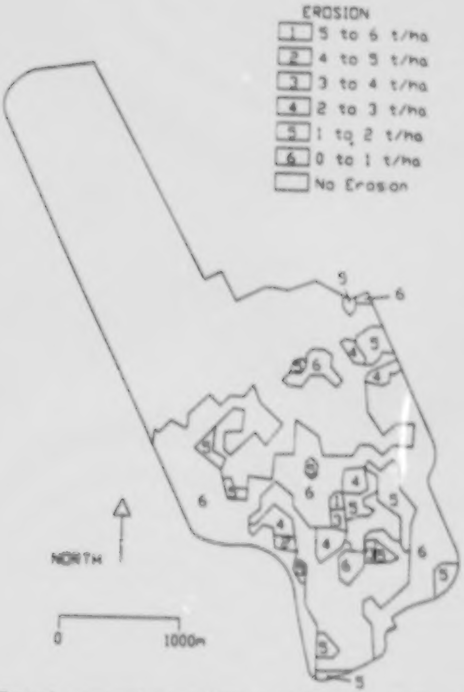
EROSION
1 5 to 6 t/ha
2 4 to 5 t/ha
3 3 to 4 t/ha
4 2 to 3 t/ha
5 1 to 2 t/ha
6 0 to 1 t/ha
No Erosion
NORTH
0
1000m
5
6
4
3
2

FIGURE 13.9. Effect of conservation practices on soil erosion: St-Dominique watershed

SUMMARY AND CONCLUSIONS

A decision support system comprising a GIS, ANSWERS and an expert system was applied to the design of a soil conservation plan for a watershed in southwestern Quebec. Sources of erosion within the St-Dominique basin were targeted using ANSWERS and a 25-year return period rainfall. Conservation efforts were focused on one hectare cells with more than one tonne of erosion. The objective of soil conservation efforts was a reduction of 50% in sediment yield and an equal reduction in average cell erosion rate.

The expert system selected appropriate conservation practices for targeted cells based on eleven rules that considered topography, land use and soil type. The selected soil conservation practices were validated using the ANSWERS model. The target reductions of 50% in sediment yield and average erosion rate were achieved.

The results of this study, as well as the field validation of ANSWERS by Montas and Madramootoo (1991), show that a DSS can be used to target erosive 'hot spots' and select appropriate soil conservation practices, which cannot be easily performed using traditional maps and data sources. The DSS is not only economic from a planning standpoint, but also provides a reliable method of utilizing scare financial resources.

ACKNOWLEDGEMENTS

The research presented in this paper was supported by the Natural Sciences and Engineering Research Council of Canada and by the "Fonds pour la Formation de Chercheurs et d'aides à la recherche" of Quebec.

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CHAPTER 14

APPLICATION OF REMOTE SENSING IN WATER RESOURCES: A REVIEW

Ivan Muzik

INTRODUCTION

The availability of water has played a crucial role in development of human societies. Even today, the amount and quality of usable water is a severe limiting factor for human development. According to Catley-Carlson (1988), "lack of clean water and adequate sanitation is a contributing factor in the death of 12.4 million people annually. That's a daily toll of 34,000 deaths, or the equivalent of fatal crashes of 100 jumbo jets each day - one every 15 minutes!" Equally devastating can be the effects of catastrophic floods.

Clearly, water resources management must be an on-going process and much effort will be necessary to alleviate existing problems. One reason for the inefficient management of water lies in our inadequate knowledge of spatial and temporal distributions of hydrologic parameters. Schultz (1988) suggested three alternatives to address this problem: (1) the collection of more, and more reliable conventional data; (2) the application of more sophisticated mathematical techniques; and (3) the use of new data acquisition techniques such as remote sensing. However, Klemes (1981) noted that "improvement of an operational (hydrologic) model requires either more empirical data or more casual input, *i.e.*, more information on the phenomenon being modelled. It cannot be achieved merely by more mathematics. The degree of mathematical sophistication has no point beyond the "carrying capacity" of the amount of the physical information available". Thus, while collection of conventional data must continue, its associated benefits may not be realized for a long period of time. To meet existing water management needs, the application of remote sensing carries the greatest potential for improving our ability to resolve conflicts and to reduce uncertainty.

For hydrological applications, the most relevant characteristics of remote sensing data are: (1) relatively high resolution in space and/or time; (2) area measurements instead of point measurements; (3) coverage of remote areas where no measurements could be obtained otherwise; (4) data available in digital form; and (5) data collected and stored centrally. This paper provides an overview of the current applications of remotely sensed satellite data in hydrological modelling and water resources management. This review includes a brief description of physical principles of remote sensing, data acquisition, and analyses.

BASIC PRINCIPLES OF REMOTE SENSING

Remote sensing can be considered as the collection of information about a target (*i.e.*, an object, area or a phenomenon) by a measuring device (sensor) which is not in physical contact with the target. While this broad definition would include techniques such as magnetometery, gravimetry, sonar and spectroscopy, the term 'remote sensing' has acquired a more restrictive meaning. It usually refers to the measurement of electromagnetic energy which is reflected and/or emitted by surface of the earth.

A distinction can be made between active and passive remote sensing depending upon the source of electromagnetic energy. An active remote sensing system, such as a radar, artificially generates a signal which is transmitted towards a target. The return signal is detected, and the difference between the transmitted and return signal is of interest. In passive remote sensing systems, sensors detect emitted or reflected natural energy from the target. The most significant source of natural electromagnetic energy is the sun.

Application of remotely sensed data can often benefit water resource analysis, engineering and management. The efficient use of remote sensing requires some knowledge of basic elements of the data acquisition process.

These components include: energy source, propagation of energy through atmosphere, energy interaction with earth features, sensors, sensor data (pictorial or numerical), data analysis, and interpretation (visual or digital). A brief discussion of these elements is provided in the following sections.

Electromagnetic Radiation

According to the wave theory, electromagnetic energy propagates through space in a sinusoidal fashion such that:

$$c = f \lambda \qquad [1]$$

where c is the speed of light (299, 893 km/s), f is the frequency, and λ is the wavelength.

It is common in remote sensing to define electromagnetic radiation in terms of its wavelength. The electromagnetic spectrum has been divided into 'bands', and each band given a name (Table 14.1). It should be noted that the infrared radiation is divided into two bands, according to its origin. The first band, 0.7 to 3 μm, is the reflected sun's infrared radiation. The second band, between 3 and 14 μm, is emitted radiation from the target and is dependent on the target's temperature. This property is called the thermal infrared radiation. The relationship between emitted radiation and thermal infrared radiation is given by the Stefan-Boltzmann law:

$$W = \sigma T^4 \qquad [2]$$

where W is the total emitted radiation from the surface of the object in Wm^{-2}, σ is a constant (5.6697×10^{-8} W m^{-2} $°K^{-4}$), and T is the absolute temperature of the emitting surface in °K.

The dominant wavelength λ_m, or wavelength at which an ideal radiator emits maximum energy, is related to its temperature T by Wien's displacement law

$$\lambda_m = \frac{A}{T} \qquad [3]$$

where A is a constant equal to 2898 μm °K.

TABLE 14.1
Electromagnetic Spectral Bands
Used in Remote Sensing

BAND	WAVELENGTH
Ultraviolet, UV	3 nm to 0.4 μm
Visible	0.4 to 0.7 μm
Infrared, IR	0.7 to 300 μm
Reflected IR	0.7 to 3 μm
Thermal IR	3 to 5 μm
	8 to 14 μm
Microwave (Radar)	0.3 to 300 cm

One can easily verify, by means of the Wien's law, that the sun (average surface temperature 6000 °K) emits maximum energy in the visible range, whereas for the earth surface (average temperature 300 °K) the maximum occurs in the thermal infrared band.

The amount of energy to be sensed and its wavelength are two very important parameters in remote sensing. In a broad sense, they relate to sensor design on one hand, and to the selection of the most appropriate band(s) to collect data for a given task on the other hand. Electromagnetic energy interacts both with atmosphere, as it travels to and from a target, and the target itself. This interaction is due to the processes of scattering, absorption and transmission which are all wavelength dependent. The atmosphere selectively attenuates radiation thus limiting the electromagnetic spectrum usable for remote sensing to the so called atmospheric windows, or spectrum bands for which atmospheric attenuation is negligible.

When electromagnetic energy reaches the earth's surface, the proportions of energy reflected (scattered), absorbed and transmitted will vary for different earth features. These differences (measured by sensors as reflected or emitted radiation) permit different features on an image to be distinguished. Moreover, the wavelength dependency means that even for a given feature (target), the proportion of reflected, absorbed (and re-emitted) and transmitted energy will vary at different wavelengths. For instance, typical spectral reflectance curves for vegetation, soil and water are shown in Figure 14.1. This radiometric differentiation of different features is the essence of remote sensing. The objectives of a particular application will influence which wavelength region to collect data from. For instance, a land use classification will select bands which are able to differentiate among different land use classes of interest. Often, several bands, or multispectral sensing, are used simultaneously to achieve better results.

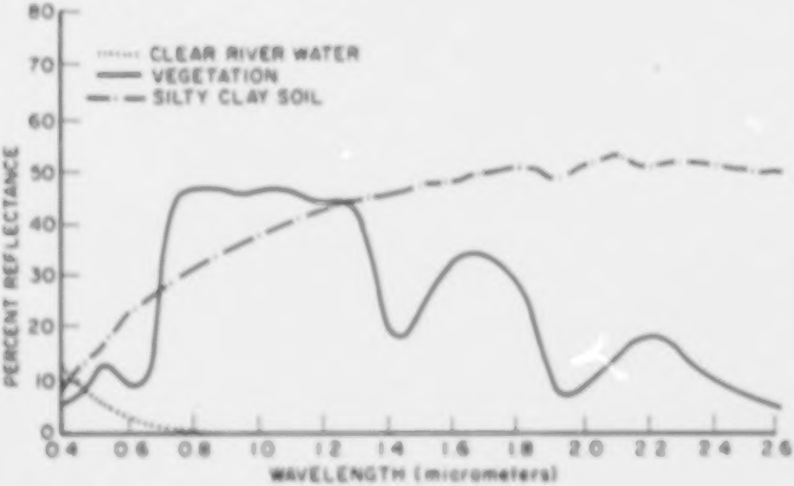

FIGURE 14.1. Spectral reflectance of bands and cover types

Data Collection Systems

There are several satellites providing data suitable for application in water resources. These satellites are either geostationary (*i.e.*, their position relative to earth does not change with time) or sunsynchronous, which follow elliptical orbits crossing near the poles.

Two geostationary satellites of interest are GOES (USA) and METEOSAT (European Space Agency). They operate from a relatively high altitude of 36,000 km and thus, the best spatial resolution these satellites can provide is only between 0.9 and 5 km. However, they have a 30 minute repeat coverage period which makes the data suitable for predicting and monitoring precipitation and flood events.

Sunsynchronous satellites most often used for water resources applications are the Landsat (USA) and SPOT (France) series of satellites. The orbits of Landsats 4 and 5 are repetitive and near-polar at a nominal altitude of 705 km at the equator. Each orbit takes nearly 99 minutes, and the spacecraft completes slightly more than 14 orbits a day, covering the entire earth every 16 days. The sensors on board the spacecraft obtain data along the ground track at a fixed width or 'swath', which for Landsat satellites is 185 km.

The Multispectral Scanner (MSS) is the primary sensor system on all the Landsat satellites. It records the solar radiation reflected by the earth's surface in four distinct wavelength bands in the visible and near-infrared portion of the electromagnetic spectrum. The radiation coming from the earth's surface is reflected by an oscillating mirror to detectors which produce a voltage related to the amount of radiation. The voltage produced is an analog signal which is converted to digital values ranging from 0 to 63. The radiance, or brightness value of an area on the earth's surface is represented by these numbers, 0 for black and 63 for white. The MSS scans across track swaths of 185 km. The analog signal is sampled during the scan at intervals which result in the picture elements (or pixels) on the imagery corresponding to a rectangular area on the ground with the 79 m side in the satellite movement direction and the 56 m side in the scan direction. The along-track scan is produced by the orbital velocity of the spacecraft itself. The sampled radiation signals are digitized, formatted into a serial data stream and stored on a magnetic tape for later transmission to earth when the satellite passes over a receiving station.

Landsats 4 and 5 (6 to be launched in mid-1992) also carry aboard the Thematic Mapper, which is a seven-band multispectral high-resolution (pixel size 30 x 30 m) scanner. It quantizes radiation into 256 brightness values, rather than 64 for MSS, thus providing a better radiation differentiation in the image.

Data Analysis

Once collected, the data usually undergo geometric and radiometric corrections before further application. The main reasons for geometric distortions are changes of spacecraft attitude (*e.g.*, roll, pitch, yaw), velocity and altitude, sensor characteristics, and the earth's curvature and rotation. These distortions are removed by mathematical operations and the image is then converted into one of the standard map projection systems, such as Universal Transverse Mercator.

Raw data also require radiometric correction to reduce errors caused by detector noise and environmental variations. Often, data enhancements are performed to improve the visual presentation of the information content of images. Examples of data enhancement are rationing two images, edge enhancement, principal component transformation, filtering, and contrast enhancement algorithms.

The final output of the evaluation of remote sensing data will be thematic information such as statistics or a thematic map. This presentation is achieved by classifying all pixels into a number of distinct classes according to their brightness values. Each class represents a certain physical attribute, such as type of land use, land cover, soil type, crop type, level of soil moisture, and range of temperature. Such classification can be done visually but digital interpretation techniques have become increasingly important.

Supervised and unsupervised approaches to digital image classification have been developed. Whereas no or minimal interaction of the operator is required for unsupervised classification, the supervised algorithms require the operator to establish a set of statistical parameters describing the spectral characteristics of the classes to be identified. These 'training' statistics are developed from areas of known types (ground truth).

REMOTE SENSING IN WATER RESOURCES ENGINEERING

Remote sensing techniques can provide valuable information for the design and operation of water resources projects. However, it is important to note that because remote sensing data do not match the accuracy of ground-based measurements, ground truthing should always accompany the acquisition of remotely sensed data. Remote sensing data can then be used to extend the ground point measurements in space and time to obtain improved estimates of hydrological features which are notoriously variable and complex. The decision to use remote sensing techniques should consider data requirements, and the availability and cost of conventional data versus remotely sensed data. The aim of this section is to summarize the use of remote sensing in those areas of water resources engineering which can be expected to provide the most benefit.

Rainfall

The use of radar for precipitation measurement is an example of active remote sensing. Radar emits electromagnetic energy in the microwave region which interacts with precipitation by means of absorption, scattering and reflection. Part of the reflected energy returns to the transmitter and can be measured. The average return power of the signal $\bar{P}_r$ is related to the raindrop diameter D by the relation:

$$\bar{P}_r = \frac{C}{r^2} \sum D^6 \qquad [4]$$

where C is a coefficient dependent on the radar type and r is the range. The difficulty in application of eqn. [4] arises from the fact that the drop size distribution in a storm is unknown. Thus, eqn. [4] is rewritten as:

$$\bar{P}_r = \frac{C}{r^2} Z \qquad [5]$$

where the so called reflectivity factor Z is related to the rate of rainfall R by an empirical equation:

$$Z = a\,R^{b} \qquad [6]$$

in which the parameters must be evaluated by simultaneous radar and rain gauge network measurements. Unfortunately, the parameters tend to vary not only aerially but also from storm to storm in the same location. Thus, while radar measurements have marked advantages, such as digitally processed areal amounts of rainfall and the ability to track the storm, they always have to be related to ground measurements for corrections.

A number of satellite techniques to infer precipitation from the visible and/or infrared imagery of clouds have been developed (Schultz and Barrett, 1989; Engman and Gurney, 1991). All these techniques are physically indirect (*i.e.*, satellites provide measurements which pertain to clouds as seen from above, rather than to the rainfall below the cloud). Typical measurements include cloud top brightness values which are converted into temperature values, areal extent of clouds, and the rate of change of cloud's areal extent. Various methods use these parameters in an empirically-based procedure or equation to provide estimates of precipitation.

While these techniques rely on empirically developed relationships, they nevertheless are all based on certain physical principles pertaining to cloud development. This point is illustrated by an equation for the accumulated rainfall ΔP during a time interval Δt derived by Ingraham (1980) as a simplified cloud development model (Brass, 1990):

$$\Delta P = -\frac{Ew\rho}{\Gamma} \ln\left[\frac{A(t+\Delta t)}{A(t)}\right] \Delta T \qquad [7]$$

in which:

E is an efficiency factor (to account for the proportion of vapour that actually condenses in the cloud),

w is the mixing ratio of air in the updraft supplying the cloud system,

ρ is the density of moist air,

Γ is the temperature lapse rate, $A(t)$ and $A(t+\Delta t)$ are the cloud top areas at times t and $t+\Delta t$, respectively, and

ΔT is the difference in temperature between the level of zero divergence in the cloud and the cloud top.

It can be seen from eqn. [7] that the rate of rainfall is related to the rate of growth of the cloud top, and the cloud top temperature (in ΔT), which both can be monitored by satellites. In general, faster cloud growth rates and cooler cloud top temperatures are associate with higher rainfall rates. The rest of the terms in eqn. [7] are usually accounted for by empirically developed relations. For details of operational satellite techniques, the reader is referred to Schultz and Barrett (1989), and Engman and Gurney (1991).

Runoff and Catchment Characteristics

Present satellites cannot measure runoff directly but the multispectral data they provide can be used to derive hydrologic parameters needed in runoff prediction, and to measure catchment geomorphological characteristics. Watershed boundary, channel length, drainage density, lakes, rivers, swamps, and the extent and time variation of flooded areas can be readily determined from satellite imagery.

The greatest success in estimating parameters for prediction of runoff by remote sensing appears to be in the area of land use and land cover classification. This application is not surprising since classification is the primary objective of image analysis. Land use/cover classes are often incorporated into hydrologic models to predict infiltration and excess rainfall rates, and eventually runoff. An example of a distributed model which uses remotely sensed data to simulate rainfall runoff conversion is Hydrotel (Fortin *et al.*, 1990). Spatial information available from remote sensing is used in this model to define 'homogeneous' hydrologic units with respect to topography, pedology and land use/cover. Such units are then assigned specific infiltration characteristics of the soil profile which are divided into three layers. The top layer is limited to about 10 cm in order to be compatible with measurements of soil moisture by remote sensing. Furthermore, data from Spot of Landsat are used to determine the length of a river.

For those preferring lumped models based on the Soil Conservation Service (SCS, 1972) runoff curve number method, classification of remotely sensed data into land use/cover classes provides a new tool, supplementing field and map data which are often the only source information. Rango *et al*. (1983) compared conventional and Landsat-derived land-use data for use in SCS type hydrologic models, and the resulting discharge frequency curves were analyzed. Landsat classification accuracy on a cell-by-cell basis (size about 1.1 acres or 0.45 hectares) was only 64 percent, but, when the grid cells were aggregated into watersheds, the classification accuracy increased to 95 percent. When both conventional and Landsat land use data were input into the HEC-1 model for generating discharge frequency curve, the difference in calculated discharge were judged insignificant for catchments as small as 2.6 km^2. For basins larger than 26 km^2, use of the Landsat approach was found to be more cost-effective than use of conventional methods. Similar results were found by Cermak *et al.* (1977), and Still and Shih (1985).

Snow Mapping

Hydrologists generally want to know the amount of water is stored in a basin in the form of snow. This information, and subsequent prediction of snowmelt runoff, can be derived from observed areal extent of snow cover, and the depth and water equivalent of the snowpack. Traditionally, snow data have been obtained manually by means of snow courses, or by snow pillow and storage gauge measurements. Remote sensing offers a new and valuable tool for obtaining snow data for predicting snowmelt runoff.

The most readily derived parameter from satellite data is the areal extent of snow cover. Until recently, satellite based snow mapping techniques have relied upon visible and/or infrared data, such as imagery supplied by NOAA from the Advanced Very High Resolution Radiometer (AVHR), and Landsat TM/MSS sensors. According to Rango (1990), the best satellite for providing highly repetitive coverage of a basin is NOAA with 2 coverages per 24 hour period. Landsat coverage is only once every 16 days. However, the poorer resolution of NOAA imagery (1.1 km) limits its application to basins larger than 200 km^2. Based on NOAA data, the U.S. National Weather Service produces operational digital maps of areal extent of snow cover on approximately 4,000 basins in North America on a weekly basis.

Two types of snowmelt runoff prediction models utilizing satellite derived snow cover extent data have evolved. The first type relies on an empirically derived relationship between remaining snow cover as of a given date and the subsequent melt water runoff (Ostrem *et al.*, 1981). This method can be used only when snow has started to melt and parts of the basin have become snow-free. Such empirical relations can be developed for many basins, but indications are that the method is limited to essentially vegetation-free areas.

The second type is characterized by the Snowmelt Runoff Model (SRM) developed by Martinec (1975). SRM requires three input variables, namely, daily values of temperature, precipitation, and snow-covered area. SRM is a distributed model in which the snowmelt calculation is based on the daily degree-day value.

Mapping snow cover using visible and/or infrared data can be limited by the occurrence of clouds which cannot be penetrated by this radiation. Furthermore, the discrimination of snow and clouds, because of their similar reflectance properties, requires special techniques. Other factors which may lead to misinterpretation are forest cover, shadows, and rocks (Engman and Gurney, 1991).

Passive microwave sensing of snow cover is a promising new technique offering a number of advantages. Microwaves penetrate clouds, thus microwave sensing is not hampered by cloudy conditions. Also, microwaves penetrate dry snow and can be used in theory to measure the depth and water equivalent of dry snow cover. Interaction of microwaves with snowpack is complex, depending on temperature, snow properties and other factors. Nevertheless, good results have been reported. In general, the microwave method requires the establishment of a relationship between microwave radiation and the snow water equivalent determined by a conventional method. Goodison (1989) assessed the utility of passive microwave data for determining snow water equivalent on Canadian prairies.

The best algorithm for prediction of snow water equivalent resulted from the regression of the microwave radiation gradient between 37 and 18 GHz [(37 - 18)/19] on snow water equivalent values determined by airborne gamma survey using U.S. National Weather Service procedure.

Other Applications

Soil moisture, evapotranspiration, groundwater, and water quality illustrate other uses of remote sensing in water resource management. More detailed information is available in Engman and Gurney (1991), and Kennie and Matthews (1985).

Both visible and infrared data have been used to measure soil moisture, but the most promising approaches are based on passive and active microwave data. In the passive microwave approach, the sensor measures the 'brightness temperature' (T_B) which is related to the soil temperature (T_s) by:

$$T_B = e\ T_S \qquad [8]$$

where e is the emissivity, $0 \leq e \leq 1$.

The microwave sensing of soil moisture utilizes the fact that the emissivity strongly depends on the dielectric constant of the soil k, which in turn exhibits a large contrast between water (k = 80) and dry soil (k = 3). For example, a change in k for a soil from 4 to 80 would result in a decrease of the soil emissivity from 0.95 to 0.6. A major problem, however, arises from the fact that the emissivity (or dielectric constant) depends on the air-soil interface. Thus, the microwave sensing provides information only on the top layer of the soil, not more than 10 cm thick. The problem, therefore, remains to correlate the top-layer soil moisture measurements with the moisture profile further below. For hydrological modelling purposes, this means to estimate the soil moisture profiles down to about 2 m. Another complication is due to vegetation cover, which attenuates microwave emission from the soil.

Active microwave sensing (radar) measures the reflected energy of an emitted signal. Surface roughness effects the soil reflectivity, whereas vegetation cover is a less important factor in active microwave sensing. The depth of measurement is still limited to the top layer of soil.

Presently, the available satellite sensors have a rather poor spatial resolution (150 km). Good resolution sensors are still too big to be flown on satellites, therefore airplanes or ground-based platforms are used presently.

Evapotranspiration is one of the most important parameters in continuous hydrologic modelling. It is also one of the most difficult parameters to measure even by conventional methods, and no effective means of measuring it by remote sensing has been developed. However, certain parameters of the energy and water balance equations, from which evapotranspiration can be computed, may be derived from remotely sensed data. These variables include surface temperature, surface soil moisture, surface reflectance, vegetative cover, and incoming radiation. A review of recent research results is found in Engman and Gurney (1991).

At present, there is no direct method of remote sensing which could detect deep groundwater aquifers. Only indirect inferential methods can be generally applied. Most of those approaches rely either on the recognition of surface water, or moisture anomalies and their related vegetational effects as indicators of possible groundwater presence, or on the interpretation of geologic and topographic information and surface hydrology (Blyth, 1985). Satellite imagery enables the geologist to view very large areas which would not be possible to achieve from ground surveys. This broad perspective helps to infer the location of aquifers from surface features such as landforms, drainage patterns, vegetation characteristics, land use patterns, linear and curvilinear features, and image tones and texture. In general, the presence of groundwater is indicated by landforms such as alluvial fans and floodplains, dense vegetation, lineaments (it is assumed that lineaments mark the location of geologic joints and faults which may contain water), medium and coarse-textured drainage patterns (indicating coarse-grained material in the basin with high infiltration rates).

Infrared imagery may be used to identify shallow groundwater and springs trough the difference in temperature between the seeping groundwater and its surroundings. Radar can be used to obtain images of topographic relief even under dense vegetation canopy.

Remote sensing can only measure reflected or emitted energy from the surface or near surface of water. Thus, there is a limit on the water quality characteristics that can be detected by remote sensing. In general, an empirical relationship between the water quality parameter and one or more spectral bands must be established for a given application. Water quality indicators such as colour, turbidity, chlorophyll, suspended solids, oil slicks and water temperature have been successfully determined from remotely sensed data and used in many water quality monitoring applications. The spatial and temporal nature of remotely sensed data is of great significance in water quality studies. In many situations, monitoring large areas on a frequent basis can only be achieved economically with remote sensing.

CONCLUSIONS

Some major areas of remote sensing application in hydrology and water management were reviewed. Many important applications were not discussed but should be mentioned. These include flood monitoring, measuring flooded areas, floodplain and wetlands mapping, monitoring lake and reservoir volumes, and the assessment of irrigated lands.

Although the application of remote sensing in hydrology did not start until 1970s, several operational techniques exist today. Some of these applications include methods for estimation of rainfall, snow mapping, and classification for land use/cover and other catchment characteristics used in runoff prediction. Much research work has allowed for limited application in other areas such as soil moisture, evapotranspiration, groundwater and water quality monitoring.

In all of the applications reviewed, remote sensing offers spatial and temporal coverage which could not be obtained by any other means. The challenge lying ahead is to develop more sophisticated mathematical models transforming remotely sensed data into hydrological parameters, and to modify existing or develop new hydrological models capable of handling essentially distributed data provided by remote sensing. The application of remote sensing techniques in hydrology and water management will grow and most likely revolutionize the discipline. One can only agree with Schultz (1988) who maintained that every hydrologist starting their career after the year 2000 will be faced with remote sensing in some way or other.

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CHAPTER 15

CONCEPTION HYDRO-ÉCONOMIQUE ET ANALYSE CONFLICTUELLE DES SYSTEMES HYDRIQUES

Charles LeBlanc et Nassir El-Jabi

INTRODUCTION

Un système hydrique est un ensemble d'éléments naturels ou artificiels, exploités suivant les conditions hydrauliques, hydrologiques et physiques existantes dans le but de réaliser les objectifs spécifiques d'un aménagement (El-Jabi et Alghabra, 1989). Un tel système peut être simple - un seul réservoir et un seul objectif (production d'énergie hydro-électrique) ou complexe -plusieurs réservoirs en parallèles et en séries, avec plusieurs objectifs et plusieurs utilisations qui influencent directement la gestion des bassins versants, par exemple: la production hydro- électrique, la réduction des dommages causés par les inondations, les consommations domestiques et industrielles, l'irrigation des terres agricoles, la navigation, et les activités récréatives.

De plus, on doit tenir compte de certains facteurs qui ne touchent pas directement la population humaine, mais n'en sont pas moins importants. Parmi ceux-ci, on peut citer l'habitation du poisson et la réduction de la concentration de pollution en aval des industries.

ANALYSE DES COMPLEXES HYDRAULIQUES

Afin de simplifier la complexité de l'évaluation des projets hydrauliques à buts multiples (PHBM), le modèle conçu, lors de ce travail, fait l'étude économique basée sur des variations mensuelles des paramètres. L'approche utilisée pour l'évaluation économique des PHBM peut être divisée en sept étapes:

Analyse Conflictuelle

L'analyse conflictuelle, faite au début de l'analyse économique d'un project, permet d'avoir une idée générale sur les scénarios qui seraient acceptés dans la réalité. Les scénarios, possibles à cette étape, ne sont qu'une évaluation des conflits qui pourraient surgir entre les différents utilisateurs de la ressource. Dans cette première étude de conflits, il faut aussi considérer les aspects particuliers de la région comme: la flore, la faune, les animaux en voie de disparition, les sites archéologiques, et bien d'autres. Cette analyse conflictuelle n'est pas obligatoire mais elle facilite et réduit de beaucoup le travail en diminuant le nombre de scénarios et en indiquant quelles solutions sont acceptables pour la ressource d'eau disponible.

Détermination des cellules hydro-électriques

L'évaluation économique des PHBM est parfois plus facile lorsque le project à étudier est divisé en régions homogènes. La région entière du projet appelé Système à grande échelle (SGE) peut être représentée comme un grand bassin versant qui par la suite est divisée en sous-bassins versants appelés aussi Systèmes à petite échelle (SPÉ). Ces SPÉ se divisent encore pour donner des cellules hydro-économiques représentant soit des usages possibles de l'eau, soit des unités géographiques homogènes. Une fois l'évaluation faite sur chaque cellule, un bilan hydro-économique peut être fait pour évaluer certaines section du projet et finalement le projet au complet. Il ne faut pas oublier que toutes les cellules hydro-économiques sont interreliées et que chacune doit être étudiées en tenant compte des autres cellules hydro-économiques (Alghabra et El-Jabi, 1990).

Détermination des conditions actuelles et futures

Dans cette étape, il faut évaluer les conditions hydro-économiques actuelles et futures. Des agences comme Statistique Canada ou autres agences gouvernementales et municipales peuvent fournir les renseignements nécessaires à l'évaluation des conditions actuelles avant la construction du projet. Par contre, les conditions hydro-économiques futures du projet sont plus difficiles à évaluer en raison des incertitudes qui s'y rattachent.

Détermination des fonctions de bénéfices

Les fonctions de bénéfices expriment les conditions hydro-économiques de l'unité en question et se modifient dans le temps afin de considérer n'importe quelle intervention dans le SGÉ. Les bénéfices de cette intervention sont la somme actualisée des bénéfices globaux de chaque périodes de temps. Ainsi, nous pouvons écrire: (El-Jabi, 1987)

$$B = \int_{0}^{T} e^{-rt} \sum_{i=1}^{I} \sum_{m=1}^{M} \Delta Y_{im}(t) \cdot P_{m}(t)\, dt \qquad [1]$$

pour $i = 1, ..., I$ et $m = 1, ..., M$
où:

B, représente les bénéfices actualisés
r, est le taux d'actualisation
$Y_{im}(t)$, est le flux de services dans la cellule i, généré pour l'usage m au temps t
$P_{m}(t)$, est le prix unitaire de l'usage m au temps t

Allocation de la ressource hydrique disponible

L'allocation de la ressource hydrique tient compte des secteurs hydro-économiques suivants: l'agriculture, les approvisionnements en eau domestique et industriel, la réduction des dommages causés par les inondations, le transport par voie navigable, la production d'énergie hydro-électrique et les activités récréatives. Cette allocation considère aussi l'évapotranspiration, l'infiltration et le débit réservé qu'on doit assurer pour l'habitat des poissons. Une fois que cette allocation est déterminée et qu'il n'existe aucun conflit apparent par rapport à la quantité d'eau, l'évaluation économique peut être alors achevée. Par contre, si on s'aperçoit qu'il existe une insuffisance au niveau de la ressource, il faut passer à l'étape suivante de la réallocation de la ressource disponible. Cette réallocation est entreprise en diminuant la quantité de la ressource de l'utilisateur ayant le rapport de rentabilité, (bénéfice par quantité d'eau utilisée, $/m³/s), le moins élevé, tout en conservant une quantité d'eau minimale. Les ajustements de la répartition de l'eau continuent jusqu'à l'élimination totale de conflits entre utilisateurs.

Évaluation économique

Les PHBM sont évalués économiquement afin de déterminer leurs rentabilités. Cette évaluation tiendra compte des coûts et des bénéfices directs et indirects. Les bénéfices indirects sont souvent mesurés en pourcentage des bénéfices directs (James et Lee, 1971). Dans cette étude, les bénéfices directs et indirects considérés sont ceux reliés aux activités suivantes: la production d'énergie hydro-électrique, la réduction des dommages causés par les inondations, le rendement accru des terres agricoles, l'augmentation de production des usines industrielles, l'augmentation du transport par voie maritime, une meilleure participation au sein des activités récréatives et la possibilité d'augmenter la quantité d'eau pour les besoins domestiques. Quant au coût du projets, seulement les coûts directs sont pris en considération par le logiciel. Rien n'empêche que les coûts indirects puissent être évalués par l'utilisateur pour avoir une évaluation économique du projet plus réelle s'il le juge nécessaire. Les coûts directs du projet sont les investissements des secteurs privé et public qui sont effectués pour justifier les infrastructures nécessaires à la réalisation du projet; comme les barrages, les routes, et l'installation du site. Aussi, parmi les coût directs, il faut tenir compte du coût d'entretien et de maintenance pour la vie du projet. Parmi les coûts indirects, il peut y avoir les coûts associés à l'environnement et aux effets néfastes du projet.

Évaluations multi-critères

Le modèle fournit une aide au décideur dans la formulation des critères de décision qu'il utilisera pour faire son choix. La méthode

ÉLECTRÉ I, ÉLimination Et Choix Traduisant la RÉalité, utilisé dans le logiciel, fut présentée pour la première fois par Benayoun, Roy et Sussman (1966). Cette méthode "permet de tenir compte, avec assez d'objectivité et de sécurité, des préférences du décideur, avec la possibilité de faire l'analyse de sensibilité en utilisant des indicateurs de concordance et de discordance". C'est une méthode qui permet de guider le choix d'un "objet" au sein d'un ensemble d'objets candidats à une sélection. Cette méthode est particulièrement adaptée au cas où le choix doit tenir compte de la qualité des objets selon plusieurs critères, et où l'on suppose ne pas pouvoir (ou ne pas vouloir) agréger ces critères en un seul (Buffet *et al.*, 1967).

CONSIDÉRATION NUMÉRIQUE: LA RIVIERE STE-CROIX

La rivière Ste-Croix, séparant la province du Nouveau-Brunswick et l'État du Maine, est un bon exemple d'un système hydrique complexe. Celle-ci sera étudiée et analysée dans le but d'identifier et d'évaluer économiquement différent scénarios de gestion acceptables aux intervenants.

Le bassin versant de la rivière Ste-Croix a une superficie de drainage de 4 230 km^2. Il est limité au nord par le bassin de la rivière St-Jean, et à l'ouest par celui de la rivière Penobscot (figure 15.1). La population du bassin, environ 20 500 habitants, est concentrée principalement au sud-est (70%) et est répartie comme suit: 62% au Nouveau-Brunswick et 38% en Maine.

Deux séries de lacs font partie du bassin versant de la rivière Ste-Croix, l'une dans la branche nord, sur la frontière canado-américaine, et l'autre à l'ouest, dans l'état du Maine. La première série, appelée lacs Chiputneticook, est constituée des lacs North, Grand, Mud et Spednic, qui se déversent l'un dans l'autre successivement avant de rejoindre le lac Grand Falls Flowage par la rivière Ste-Croix. Dans la deuxième série, les lacs Junior et Sysladobsis s'écoulent dans le lac West Grand, qui se déverse à son tour avec le lac Clifford dans le lac Big, pour enfin aboutir dans le lac Grand Falls Flowage (figure 15.1).

L'écoulement du lac Grand Falls Flowage passe à travers le barrage de Grand Falls à Kellyland (É.-U.) et le lac de Woodland, ensuite par le barrage de Woodland et l'usine de pâte et papier appartenant à Georgia

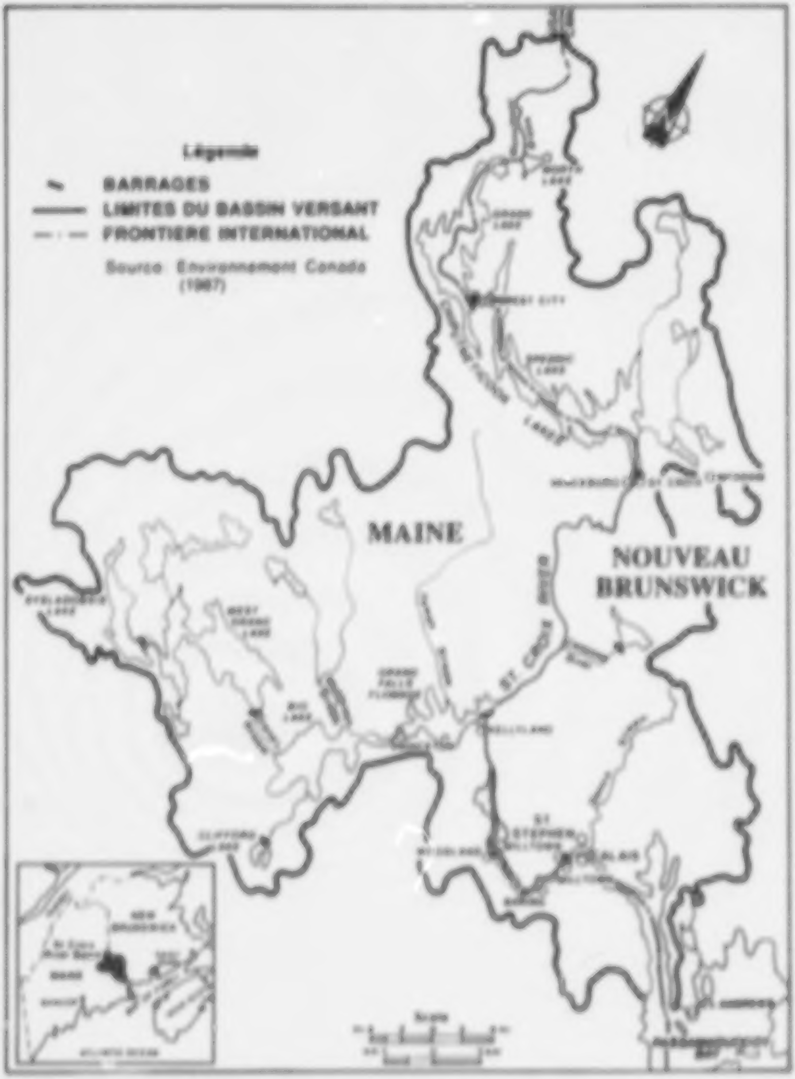
Légende
BARRAGES
LIMITES DU BASSIN VERSANT
FRONTIERE INTERNATIONAL
Source: Environnement Canada (1987)
MAINE
NOUVEAU BRUNSWICK
ST CROIX RIVER

FIGURE 15.1. Bassin versant de la rivière Ste-Croix

Pacific Corporation (GPC). Cette masse d'eau traverse ensuite les villes de Baring (E.-U.), Milltown (E.-U.), Milltown (Canada), St-Stephen (Canada) et Calais (E.-U.), avant de se jeter dans la Baie de Passamaquoddy. Son parcours total, du lac Grand jusqu'au lac St-Stephen est de 124 km avec une dénivellation de 129.2 m.

ÉCONOMIE DU BASSIN

Les principales activités économiques dans le bassin sont l'industrie de la transformation du bois, la pêche, l'agriculture, le tourisme, les activités récréatives, et les services gouvernementaux. Il y a également deux centrales hydro-électriques opérées par GPC, l'une située à Grand Falls, et l'autre à Woodland, produisant une énergie moyenne annuelle de 64 880 MW-h pour un revenu brut annuel de 2.3 millions de dollars ($ de 1987). Enfin, une troisième centrale hydro-électrique, produisant 19 500 MW-h seulement, est opérée par Énergie N.-B. à Milltown.

Outre l'aspect énergétique, l'utilisation principale de la rivière Sainte-Croix demeurent les activités récréatives aquatiques; pêche à la ligne, canotage, bateau de plaisance, camping, et autres sports de plein air. Ces activités, ainsi que le tourisme, qui contribuent à l'économie de la région, sont favorisées par son appartenance au groupe des rivières patrimoines du Canada. Afin de les promouvoir davantage, une section située au nord-est du bassin a été désignée comme zone récréative, contrôlée par la "Ste-Croix Waterway Joint Advisory Commission" (SCWJAC).

La pêche est considérée comme l'activité récréative la plus pratiquée sur ce bassin. On estime le nombre de pêcheurs à 13 000 pêcheurs-jour par année, ce qui génère un revenu annuel de plus de 1.3 millions de dollars (Environnement Canada, 1987). Cet estimation ne comprend pas le revenu des pêcheurs de la région.

De plus, 6 000 canoteurs empruntent annuellement le parcours de la rivière Ste-Croix. La majorité commence leur descente à Vanceboro, et ont accès en route à de nombreux camps situés le long de la rivière. Le bassin compte plus de 200 sites de camping, dont 60 au Parc Provincial sur le lac North, 36 sur le lac Spednic, 111 sur la Baie de Oak près de St-Stephen, et 20 autres répartis sur d'autres lacs.

Quant à la consommation en eau domestique et industrielle dans le bassin versant, elle varie selon le milieu rural ou urbain. Ainsi, même si les grandes villes du sud-est ont toute leur propre système de distribution d'eau, environ la moitié de la population se sert de puits privés pour son approvisionnement.

RÉGULATION DES DÉBITS ET DES NIVEAUX D'EAU DES LACS

Le bassin versant de la rivière Ste-Croix est présentement bien régularisé, afin d'atteindre les objectifs suivants: d'abord, augmenter la production d'énergie hydro-électrique en gardant le niveau d'eau du lac Grand Falls Flowage élevé; ensuite diminuer les effets néfastes des sécheresses et des inondations, et maintenir un débit adéquat pour l'habitat du poisson. Ces régulations ont été mises en place par différents organismes gouvernementaux afin de faciliter l'opération des structures de contrôle et de satisfaire une majorité de la population. La quasi-totalité des barrages sont appartenus et contrôlés exclusivement par GPC. Les règles d'opérations des structures de contrôles des réservoirs situées sur la frontière ont été établies par la Commission Mixte Internationale (CMI) en 1965, et sont maintenues conjointement avec GPC, avec l'approbation de la population du bassin. L'autorité de la CMI se limite au lac Grand, au lac Spednic, et à la rivière Ste-Croix.

D'autres organismes gouvernementaux ont aussi des règlements en ce qui concerne les débits de la rivière. Par exemple, en aval de Woodland, la United States Environmental Protection Agency (USEPA) requiert un débit minimum de 21.2 m^3/s, afin de diluer l'effluent de l'usine de pâtes et papiers située à Woodland. Ceci permet de maintenir une concentration d'oxygène égale ou supérieure à 5 mg/l, ce qui suffit pour assurer la survie des poissons. De fait, il existe des règlements pour pratiquement tous les lacs majeurs du bassin (huit lacs en tout) quant au niveau du lac (minimum/maximum), ainsi qu'au débit minimal de la rivière Ste-Croix (tableau 15.1). Les exigences actuelles des organismes gouvernementaux sont journalières, c'est-à-dire qu'elles font appel à un débit quotidien moyen. De plus le "Department of Environmental Protection" (DEP) de l'État du Maine recommande un débit de 27.5 m^3/s en aval du barrage à Woodland durant les mois d'été. Enfin, les canoteurs préféreraient un débit minimum, à Vanceboro, de 12.7 m^3/s.

TABLEAU 15.1
Régulations des lacs (réservoirs)

Lac/Barrage	Élévation min. (m)	max (m)	Débit min (m³/s)	Surface de drainage (km²)	Régulateur
Grand/ Forest city	130.436	132.57	2.12	357	CMI, FERC, M.D.P.G.
Spednic/ Vanceboro					
1 oct.-30 avr.	115.233	117.61	5.66	1 080	CMI
1 mai-30 sept.	114.757	117.61	5.66	1 080	CMI
Grand Falls Flowage/ Grand Falls	60.580	62.106	24.1	3 420	P.S
Élévation de la rivière Ste-Croix/ Woodland	42.468	43.077	21.2	3 500	U.S.EPA
Sysladobsis/ Dobsis	91.757	93.153	P.S	161	P.S
Grand Lac Ouest/ Grand Lake Stream	89.614	91.870	2.83	580	MDIFG
Clifford	67.969	70.136	.142	26.3	MDIFG
Canoose Flowage/ Canoose	94.11	96.001	.142	132	P.S

M.D.P.G.: MAINE DEPARTMENT OF FISHERIES AND GAMES
FERC: FEDERAL ENERGY REGULATORY COMMISSION
MDIFG: MAINE DEPARTMENT OF INLAND FISHERIES AND GAMES
P.S: PAS SPECIFIE
U.S.EPA: UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

ANALYSE CONFLICTUELLE

Parmi les divers conflits existant dans le bassin, on peut noter celui qui oppose les résidents saisonniers du lac Spednic à la GPC (Environnement Canada, 1987), pendant les périodes de sécheresse notamment. Les besoins de la GPC sont liés à la production d'énergie et aux exigences du DEP, alors que ceux des résidents saisonniers sont plutôt de nature esthétique et récréative. Ces derniers trouvent que les régulations existantes sont insatisfaisantes; leurs arguments principaux sont les suivants: (1) l'accès au lacs par bateau limité pendant les périodes sèches; (2) l'abaissement du niveau de la nappe phréatique lorsque le niveau du lac est bas; (3) l'érosion du rivage du lac à cause du changement saisonnier du niveau d'eau; (4) échouage des poissons dans les eaux peu profonde lors d'une baisse brusque du niveau d'eau du lac; (5) esthétique riveraine, et (6) pertes commerciales des divers camps.

L'organisation SCWJAC a permis une diminution de ces conflits, grâce à une communication accrue entre les gouvernements et les différents organismes concernés. Mais en essayant de développer le tourisme et les activités récréatives dans le bassin, la SCWJAC pourrait créer de nombreux conflits: (1) entre les résidents et les non-résidents; (2) entre les divers groupes; (3) entre les pêcheurs et les campeurs pour les sites de camping; (4) entre les canoteurs et les pêcheurs sur les lacs Chiputneticook et finalement, et (5) à cause de la production accrue des déchets dans le bassin.

Une autre source de conflit est liée aux passes à poissons dans les barrages. Plusieurs études ont constaté qu'elles sont inadéquates, et qu'il serait nécessaire de les améliorer pour augmenter le nombre de poissons en amont. Aussi, pendant les périodes de sécheresses, où le niveau d'eau des lacs est très bas, beaucoup de poissons meurent en passant à travers les turbines pour retourner dans la Baie de Fundy.

L'analyse de la structure conflictuelle entre les usages de la rivière Ste-Croix se fera en deux étapes. Tout d'abord, on éliminera tout scénario considéré comme impossible (Fraser et Hipel, 1987). Ensuite, les scénarios retenus seront étudiés et analysés. La rivière Ste-Croix est influencée par plusieurs groupes qui ont chacun leurs propres objectifs. Ces groupes sont:

(1) - **U.S.EPA et Ministère des Pêches et Océans du Canada (MPO):**
Objectifs:

- Augmenter le débit au barrage de Woodland à 27.5 m^3/s
- Modifier et/ou reconstruire quelques passes à poissons.

(2) - **SCWJAC:**
Cet organisme a comme rôle d'assurer que la rivière internationale reste intact,et qu'aucun groupe ou industrie ne modifie son parcours, sa qualité ou sa quantité. Tous les nouveaux règlements ou contrôles doivent être évalués par lui.

Objectifs:

- Optimiser les ressources hydriques et essayer de satisfaire plusieurs groupes en considérant les aspects socio-économiques et environnementaux.
- augmenter le débits minimum à l'aval de Woodland à 24 m^3/s pour la saison d'été, sauf dans les périodes de grande sécheresse, où il serait maintenu à 21.2m^3/s.
- donner plus d'eau aux canoteurs en leur fournissant un débit de 10 m^3/s pour quelques fin de semaines, à raison de deux jours par semaine sauf dans les temps très secs.
- essayer de diminuer les grosses variations du niveau d'eau au lac Spednic.

(3) - **GPC:** Cette compagnie joue un rôle très important dans la régulations des lacs et des réservoirs et l'entretien des passes à poissons, à cause de son importance en tant qu'employeur: Une réduction de sa production l'obligerait de mettre à pied une partie de sa main-d'oeuvre, ce qui aurait des conséquences néfastes sur la population du bassin.

Objectif:

- Maintenir les régulations existantes et pas modifier les passes à poissons.

(4) - **Résidents saisonniers au lac Spednic:**

Objectif:

- Modifier les régulations existantes afin de réduire les grandes variations du niveau d'eau du lac Spednic. Un niveau minimum de 116.18 m serait préférable à 114.8 m durant la période de juin à septembre.

(5) - **Canoteurs:**

Objectif:

- Augmenter le débit passant à travers le barrage de Vanceboro; ils demandent un débit minimum de 12.7 m^3/s au lieu de 5.66 m^3/s durant les mois d'été.

(6) - **Pêcheur à la ligne:**
Objectif:
- Réduire les grandes variations des niveaux d'eau des lacs;
- Plus d'eau dans la rivière pendant la saison de pêche.

L'analyse conflictuelle a donné trois scénarios possibles sans qu'il y ait de conflits entre les groupes. Ces scénarios sont:

(1) - Débits à Woodland de 27.5 m^3/s avec des modifications des passes à poisson, donner un débit de 12.7 m^3/s aux canoteurs, et satisfaire aux exigences des pêcheurs.

(2) - Optimiser la ressource avec modifications des passes à poisson, donner un débit de 12.7 m^3/s aux canoteurs, et satisfaire aux exigences des pêcheurs.

(3) - Optimiser la ressource en fournissant un débit de 12.7 m^3/s aux canoteurs.

ÉVALUATION HYDRO-ÉCONOMIQUE DES SCÉNARIOS RETENUS

Cette évaluation se fera à l'aide du logiciel CAO/PHBM Alghabra et El-Jabi (1990) et LeBlanc, (1991) et qui tient compte du rendement économique de plusieurs consommateurs d'eau de différents secteurs (e.g., agriculture, production hydro-électrique). Présentement, ce logiciel a la capacité d'étudier dix secteurs (cellules hydro-économiques) et ce nombre pourrait augmenter au besoin. Dans le module d'agriculture, dix types de cultures peuvent être étudiées à la fois pour chaque secteur et ce nombre pourrait également être augmenté.

Les scénarios retenus contiennent quelques suggestions pour modifier les régulations existantes. L'une d'elles est d'avoir un débit minimum de 27.5 m^3/s (plutôt que 21.2) en aval de Woodland pendant les mois d'été. Comme la GPC assure sans grande difficulté un débit minimum de 24.1 m^3/s à Kellyland, en amont de l'exigence de 27.5 m^3/s à Woodland presque à 100% du temps (objectif U.S.EPA et MPO). Une autre suggestion porterait le débit en aval de Vanceboro de 5.66 m^3/s à 12.7 m^3/s pour les saisons d'été.

Après exécution du logiciel CAO/PHBM pour simuler le comportement des lacs Grand et Spednic ainsi que la rivière St-Croix, pour les données des années 1969 à 1985, on constate qu'un débit de 12.7 m^3/s en aval de Vanceboro ne pourrait pratiquement jamais être atteint à cause d'un manque d'eau. Le tableau 15.1 indique le nombre d'années, entre 1969 et 1985, où les régulations de plusieurs débits minimums auraient pu être satisfaites durant toute l'année en aval de Vanceboro. Selon cette simulation, un débit 5.66 m^3/s pourrait toujours être satisfait pour l'année entière, tandis qu'un débit de 12.7 m^3/s ne le pourrait jamais.

Le troisième et le dernier scénario, proposé par SCWJAC, essaie de satisfaire à plusieurs groupes à la fois. Elle propose entre autres, pour les canoteurs, un débit minimal de 10 m^3/s deux jours par semaine, en aval de Vanceboro. Ceci donnerait un débit minimal moyen pour la semaine de 6.9 m^3/s; l'analyse démontre que ce débit pourrait être satisfait à 90% du temps, à condition qu'aucun changement climatique ne se produise. Ce débit minimal de $10 m^3/s$ aurait également l'avantage de répondre en partie aux exigences des pêcheurs. Même la population vivant près du lac Spednic serait avantagée lors des sécheresses. Les activités récréatives comme le canotage et la pêche seraient ainsi limitées pour conserver l'eau tout en tenant compte des demandes faites par la GPC pour leurs centrales hydroélectriques.

En somme, parmi les scénarios étudiés, celui de la SCWJAC est le meilleur du point de vue social et environnemental, ceci pour une ressource d'eau limitée. Le coût estimé de la mise en place ce scénario est de 6.5 millions de dollars (Sochasky, 1991).

L'analyse de ce projet sur le plan économique, à l'aide du logiciel CAO/PHBM évalue le rapport B/C à 2.74 pour une vie économique de 18 ans, un taux d'actualisation de 10%, et un coût annuel d'entretien et de maintenance à 10% du coût de construction. Le taux de rentabilité interne, évalué à partir des paramètres ci-dessus, est égal à 7.59% (figure 15.2).

CONCLUSION

La méthodologie et le logiciel ont été conçus dans le but de pouvoir faire diverses analyses, qui aideraient les décideurs à vérifier si leurs PHBM sont économiquement rentables, en surveillant à la fois les aspects sociaux et

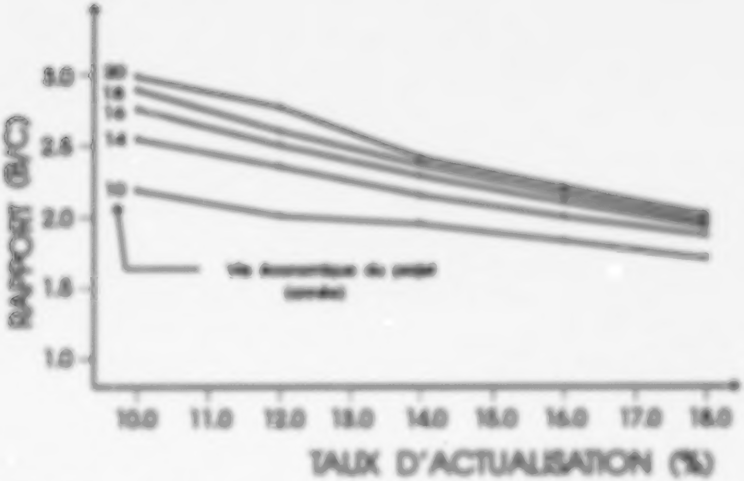

FIGURE 15.2. Taux d'actualisation et rapport (B/C)

environnementaux. Ce modèle permet à l'utilisateur d'évaluer les bénéfices du projet à l'étape de la pré-faisabilité. Les bénéfices qui peuvent être évalués à l'aide du modèle sont: l'agriculture, la consommation domestique, la consommation industrielle, les réductions des dommages causés par les inondations, les activités récréatives, la production hydro-électrique et le transport par voie navigable. Ce modèle a aussi la capacité de faire un bilan hydrique global de la région afin de déterminer si la quantité de ressource hydrique disponible du bassin est suffisante pour satisfaire à tous les utilisateurs. Il faut aussi tenir compte du débit minimal dans la rivière pour l'habitat du poisson.

La rivière Ste-Croix, séparant l'État du Maine et la province du Nouveau-Brunswick, a été depuis longtemps sujette à de nombreux conflits entre les utilisateurs de la ressource d'eau limitée. Ceci apporta de nombreuses régulations des niveaux d'eau et du débit sortant des lacs.

Parmi les scénarios analysés, celui proposé par SCWIAC a été jugé le meilleur. Ce scénario a pour but principal d'essayer de satisfaire à la plupart des groupes en changeant les régulations existantes. Les nouvelles régularisations proposées sont de modifier celles du lac Spednic en augmentant le débit durant la fin de semaine à 10 m³/s pour les mois d'été. De nouvelles régularisations sont aussi proposées en aval de Woodland. Elles ont comme objectif d'augmenter le débit minimal à 24 m³/s pour les mois d'été. Dans la proposition de SCWIAC, il est aussi question de construction d'infrastructure, de passes à poisson, de nouveaux sites pour camping et d'agrandissement des sites de camping pour les canoteurs. Cette proposition est trouvée non seulement très satisfaisante pour les utilisateurs du bassin mais aussi très rentable économiquement, avec le rapport B/C égale à 2.74 pour la vie économique de 18 ans et un taux d'actualisation de 10 % en appliquant le logiciel CAO/PHBM. Elle est aussi très bien acceptée sur le plan environnemental et semble libre de conflits.

REMERCIEMENTS

Le soutien financier de cette étude fut partiellement accordé par le Conseil en Sciences naturelles et en Génie du Canada.

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CHAPTER 16

APPLICATIONS OF STOCHASTIC HYDROLOGY FOR WATER RESOURCE SYSTEM OPERATIONS AND PLANNING

Peter J. Rae and Bruce I. McClennan

INTRODUCTION

Normal practice for the design of water resource systems has been to use the available streamflow record as the best possible estimate of future flows expected at sites within a river basin. The defect in this analysis is that the recorded data is only one sequence out of an infinite population of possible future streamflow sequences. This practice may result in design or system operations being tailored to the historical data, since future streamflows are unlikely to reoccur in exactly the same sequence as experienced in the past. The single historical record also gives only one estimate of the system firm yield and no measure of its reliability.

Stochastic time series analysis attempts to overcome these difficulties by providing a means of generating a number of possible streamflow sequences which can be used for evaluating a water resource system. This evaluation provides a basis for reliability analyses using multiple independent sequences and permits a water resource manager to base decisions on probabilistic analyses. It is one of the best methods of informed decision making in the face of uncertainty.

Over the past 2 decades, there have been significant research efforts to develop stochastic time series methods for use in water resources analysis. For a number of reasons, little of this research has been developed into a form suitable for general hydrologic engineering design practice. Perhaps most importantly, the techniques have not been available in easily understood formats with suitable software and documentation. In addition, the benefits of stochastic methods have not been fully recognized by the design community.

This paper summarizes the results of a recent study by Acres International Limited for the Canadian Electrical Association (Acres, 1990) as Project Number 720 G 682. The study tested various stochastic techniques and software for their application to practical water resource problems. More detailed objectives of the study are described in the following section.

STUDY OBJECTIVES AND APPROACH

The overall objective of the study was to evaluate stochastic streamflow generation computer programs based on criteria reflecting both the character of the generated sequences and the ease of application of the programs evaluated. The intent of the study was to evaluate computer program packages (numerical models) rather than examining the more fundamental mathematical model formulations.

For complex multi-reservoir systems, the generated streamflows must preserve the essence of the historical streamflow record, including statistical characteristics such as the mean, standard deviation, serial correlation and cross correlation. Other characteristics which describe the character of the data are also of interest for design application. These often include higher order moments of the data and the frequency of runs and run sums which indicate drought sequences. These latter statistics may not be explicitly accounted for in the design of the model, but have an important bearing on the reservoir storage requirements, firm yield and system reliability calculations.

The study included a review of the state-of-the-art for stochastic time series methods to identify models which have been suitably documented and supported. Four stochastic models were selected for evaluation and used to generate multi-site streamflow data sequences for two test river basins. A first level of model evaluation was carried out by comparing the generated streamflow sequence statistics with historical streamflow statistics. A second level of model evaluation compared estimated firm and average energy characteristics, resulting from the generated and historical streamflow sequences for hypothetical hydroelectric systems. Similar characteristics could have been used to satisfy other operating objectives such as water supply or irrigation.

The results of the study will assist in the selection of models for use in water resource operations and planning. These models can be used to reduce uncertainty by allowing decisions to be made on a probabilistic basis.

STATE-OF-THE-ART IN STOCHASTIC MODELLING

The literature on stochastic hydrology consists of an extensive body of research and applications by investigators worldwide. While the literature includes many sample applications, most of the available mathematical models have not yet made the transition to common use. A comprehensive literature review was carried out as the first stage of the study (Acres, 1990). The literature review was designed to locate suitable multivariate models, as well as to define the theoretical background to the analysis. The study examined multivariate models because of the importance of the complementary interaction among sites which occurs in complex multi-reservoir systems. Models capable of generating monthly flow data were selected because these data are often used in design and operations applications.

When generating sequences of monthly flows, it is important that the selected stochastic model preserves characteristics of the recorded flow series appropriate to the system being studied. For example, it is extremely important to have a good description of the distribution of the monthly flows for the calculation of firm power at a run-of-river site. However, for large storage sites, it is more important to correctly model the distribution of the annual flow volumes. None of the models reviewed are capable of explicitly preserving all the possible streamflow characteristics of interest simultaneously. Many available models can, however, implicitly reproduce important characteristics of the time series which are not explicitly provided for in the model design.

In recent years, two basic approaches have evolved for generating monthly streamflow sequences. Disaggregation models first generate annual flows at one site, and then disaggregate temporally and spatially into monthly flows at related sites. The other approach is based on the Box Jenkins family of models which generate monthly flows at all sites using parameters which typically vary from month to month.

The major advantage of the disaggregation models is that the distribution of the annual flow volumes is specifically modeled, and hence variance and any observed persistence can be preserved. The overall disaggregation model is typically comprised of two linked submodels. The annual model generates annual flow volumes taking account of serial and cross correlations. The annual flow volumes are then used to create monthly flows at each site with a disaggregation scheme. More than one level of disaggregation is employed in some applications to provide for streamflows at all required sites.

The direct models are a logical extension of the ARIMA family of models in a seasonal multivariate form. The model relates monthly flows to those of the previous months and random components for the present and previous months.

Development of multi-site flow generating models has been occurring in several different areas. It appears intuitively appealing that a model can be developed which generates monthly flows directly and also mimics the behaviour of the annual flows without having recourse to disaggregation procedures. However, from a practical standpoint, it would appear that the models incorporating disaggregation procedures are currently more thoroughly developed and successfully tested. The ability to model the autocorrelation of annual flows can be important in estimation of system firm energy and storage requirements.

One difficulty with the concept of a disaggregation model is the lack of a physical basis. That is, annual flows in nature are derived by the aggregation of shorter term flows in subbasins. Disaggregation, however, seeks to determine the multi-site flows in reverse from an annual basin aggregate flow which is spatially and temporally disaggregated.

Multivariate Models in Computer Program Form

As a result of the literature review, the following models were located as computer program packages.

Model	Developer	Type
HEC-4	US Army Corps of Engineers	Direct - regression
SPIGOT	J. Stedinger, Cornell Univ., New York	Disaggregation
NATAL	G. Pegram, Natal Univ., South Africa	Disaggregation
CARMA	Various	Direct
LAST	US Bureau of Reclamation	Disaggregation
CEPEL	Pereira, Brazil	Disaggregation

The models are briefly described in the following paragraphs. More detailed descriptions can be found in the source study (Acres, 1990).

HEC-4

Early work by Beard (1962; 1965) led to the development of HEC-4 (U.S. Army Corps of Engineers, 1971), one of the family of programs developed by the Hydrologic Engineering Center. HEC-4 is a multivariate AR(1) model which generates monthly flows directly using regression techniques. The model preserves the monthly mean, standard deviation, skewness coefficient and lag-one autocorrelation. The model will not explicitly preserve the structure of the annual data, since it generates monthly flows directly.

The model does not allow any latitude in the selection of data transforms or mathematical model parameters. In addition, the monthly flows are adjusted after generation of the synthetic data series so that the mean and standard deviation of the record matches the historical record. This process eliminates variability between the means of the generated sequences and, therefore, does not provide a range of possible hydrologic characteristics. The synthetic record only indicates variability in the details of the monthly flows.

LAST

The LAST program (Lane and Frevert, 1988) incorporates a two-tiered disaggregation procedure. The package is a suite of programs run individually by the user which lead, ultimately, to the desired generated sets of data. The program provides modules for exploratory data analysis, streamflow transformation, parameter fitting, generation of streamflows and evaluation of the final sequences. The embedded mathematical model is based on the Matalas model (Matalas, 1967). Disaggregation procedures use the Valencia-Schaake model.

The watershed system is divided into key stations and substations with each substation associated with a key station. Flows at the substations to a key station will often sum to the flow at the key station. Cross correlations between key stations are explicitly modeled, while those between the various key station's substations are only reproduced implicitly.

SPIGOT

The SPIGOT (Grygier and Stedinger, 1989) model was developed from work carried out at Cornell University and uses staged disaggregation procedures. SPIGOT treats a group of gauged sites as an interrelated system. Each system must have one aggregate site, and may have a number of key sites and control points. Key sites differ from control points in that flow series are generated at all key sites before they are generated at any control points, and cross correlations among key sites are explicitly preserved. Flow series at control points are generated from the key site flows, but the cross correlations between pairs of control points with different key sites are preserved only implicitly.

For each site and month combination, there are three terms which can appear in the multivariate annual to monthly model: the lag-one monthly flow at the same site, the annual flow at the aggregate site, and the weighted average of flows in all previous months (surrogate flow). A constant term will always appear in the model. The surrogate flow improves serial correlation and ensures that the sum of the monthly flows is close to the corresponding annual flow.

NATAL

The NATAL program was developed at the University of Natal for use in studies of the Vaal River system in South Africa (Pegram, 1986). The model uses an ARMA(1,1) multivariate model to determine the annual flows which are disaggregated to monthly values using the method of fragments.

The program is designed as a series of modules which are executed in turn to produce the required flow series. Individual flow series are transformed to normal using one of the 'Johnson' transforms (Hill *et al.*, 1976). A univariate ARMA(1,1) model is fitted to each of the transformed annual flow series and the residuals computed. The multivariate character of the model is estimated by preserving the cross correlation of the residual series derived from the univariate models in the overall model. This process used a cross correlated random component in the model. The generated normal variates are transformed back to annual flow values. Annual volumes are temporally disaggregated using fragments for each gauge selected by least squares. The same year is used to create all fragments.

CARMA

A contemporaneous autoregressive moving average (CARMA) model is a special case of the general multivariate ARMA model. The CARMA form is a relatively simple and efficient model which can be used for direct generation of monthly flow data. Conceptually, the model is decoupled into component equations so that univariate estimation procedures can be employed. These are now well established (Hipel *et al.*, 1977).

The order of the model is defined by fitting a univariate model to each flow series using a three-stage iterative process of model identification, parameter estimation and diagnostic checks. The univariate residual series are then used to calculate the cross correlation structure. If only the lag-zero cross correlations of the residuals resulting from the univariate models are significantly different from zero, then the CARMA model is adequate. If this is not the case, then a more complex model is required.

Camacho *et al.* (1985) suggest that more efficient parameter estimates are obtained by using the univariate model parameters and the residual cross correlation matrix as a tentative model, and then using general multivariate ARMA estimation procedures to determine the final model parameters. An approximation to this process is the adoption of the tentative model itself.

The construction of a stochastic model in this manner allows for a great deal more flexibility than some of the disaggregation programs. The simplest possible model can be selected to suit the actual data being studied. The *a priori* model selection used by the SPIGOT, HEC-4, CEPEL, LAST and NATAL programs has the disadvantage that the model may not suit the data. The CARMA approach is based on building a model which is determined by the requirements of the data itself.

CARMA estimation and flow generation routines have been presented in the literature by Camacho *et al.* (1985). While these procedures are theoretically very attractive, they have not yet made the final transition to a general-use computer program package.

TEST BASIN SELECTION

The evaluation of the models used streamflow data for two watersheds. Streamflow records were screened to identify basins across the country with an adequate length of record at several locations in the watershed. On this basis, the Bow River basin in Alberta and Rivière Saint-

Maurice basin in Quebec were selected as test basins. Naturalized flow data were available from TransAlta Utilities Ltd. for the Bow River and from Hydro Quebec for the Rivière Saint-Maurice. The two basins provided diversity in their size and topographic features, as well as significantly different climatic influences.

MODEL EVALUATION

The HEC-4, SPIGOT, LAST, NATAL and CARMA programs were used to generate stochastic streamflow sequences for the two test basins. Only a limited amount of work was carried out with the LAST model to assess the ease of use and potential of the package, since a complete microcomputer version was not available. Except for the CARMA model, the program packages tested can be used for data transformation, model selection, parameter estimation and streamflow generation. All of the models offer some degree of automation in the process which constrains the user to certain preselected model features. A series of separate program routines were used to build up the CARMA model.

Periods of record of 10, 25 and 50 years were used in model fitting to illustrate the effect of record length on model results. The shorter records were selected as subsets of the original 50-yr data set. The three record lengths were selected to evaluate the performance of the models over the range of data which might be available for users with practical applications. Forty data sequences were generated with each of the models for each period of record.

Model Verification

Model verification evaluates the ability of the programs to reproduce the historical streamflow distribution. This includes tests of the monthly and annual mean, standard deviation and cross correlation structure for each gauge in the test basins. Run sums were tested to complement the serial correlation structure of the models. Each of the statistics tested produces a single value for each streamflow sequence. The sampling distribution of the generated sequences can be compared to the value of the particular statistic of the historical sequence using a Box-plot as illustrated in Figure 16.1.

Figure 16.1 is typical of the verification tests in the study. The figure shows the monthly and annual mean and standard deviation for one gauge, period of record and model. The plot shows that almost all historical values fall within the interquartile range of the sampling distribution.

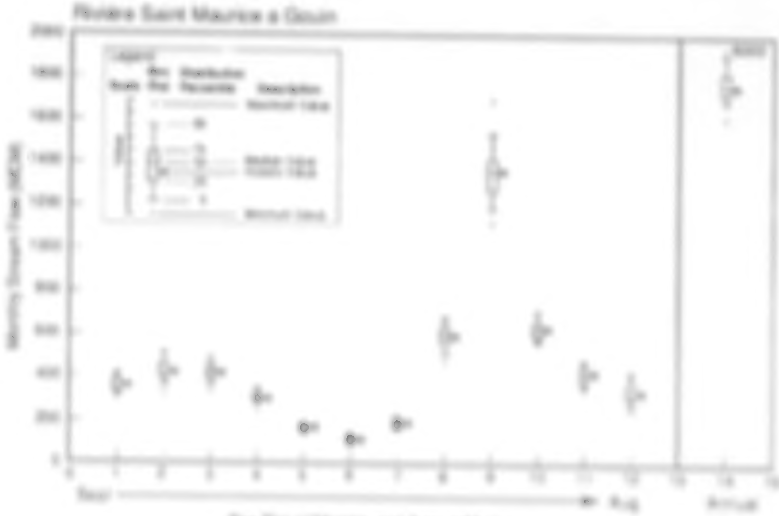
While the historical value can theoretically fall at any point within the population sampling distribution, a verifiable model was assumed to be achieved if the historical value fell in the vicinity of the interquartile range. This recognizes the implicit bias in the model design which arises because the parameters are based on the historical data.

For verification, a comparison of the sampling distributions of the selected streamflow test statistics shows that the NATAL model most frequently gave results with the historical value between 25 and 75 percentiles. The SPIGOT model also consistently produced results where the good sampling distribution includes the historical value.

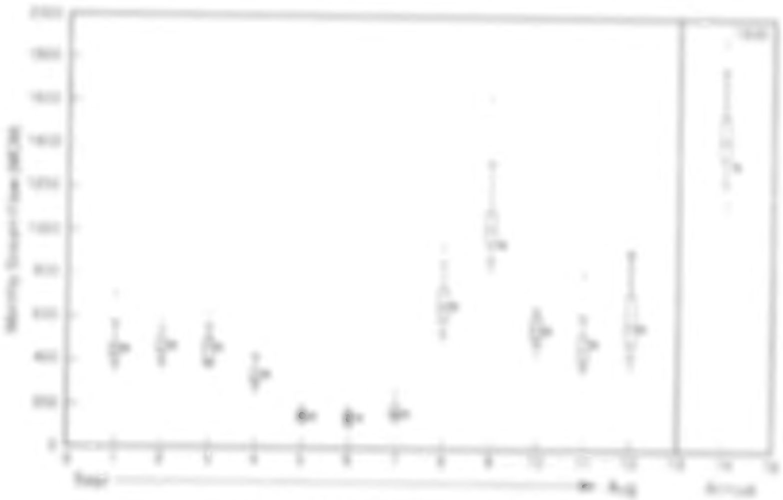
The CARMA model produced good estimates of statistics other than those dependent on the cross correlation structure. The selected model was not periodic monthly and was not expected to reproduce this data well. A more rigorous application of the model, including multivariate parameter estimation, could potentially improve the test results.

The HEC-4 model did not produce a sampling distribution of means or standard deviations which reflected the range of possible events. The model produced similar results to the other models for the correlation structure.

It is important to note that these relative comparisons were consistent for both the Bow and Saint-Maurice basins. This indicates the model can be expected to perform in the same way over the range of typical Canadian hydrological conditions.



Box Plot of Monthly and Annual Means



Monthly and Annual Standard Deviations

FIGURE 16.4. Evaluation of monthly flow generation models SPIGOT monthly flow statistics

Model Validation

Model validation was carried out to indicate how well the models can generate streamflow sequences which reproduce characteristics required for different operating objectives. The focus was therefore not on the streamflow characteristics themselves, but on the characteristics of the different operating objectives. Two water resources operating characteristics were used in the analysis–storage yield and energy yield.

STORAGE BASED VALIDATION

Storage validation measures consisted of the minimum monthly run sums, storage deficit and station yield as a function of storage capacity. Run sums are simply the cumulative monthly flow volumes of various durations. The statistic gives the severity of the worst drought sequence in each streamflow record. Figure 16.2 shows a comparison of generated and historic run sums at the basin outlet. Note that the model successfully reproduced

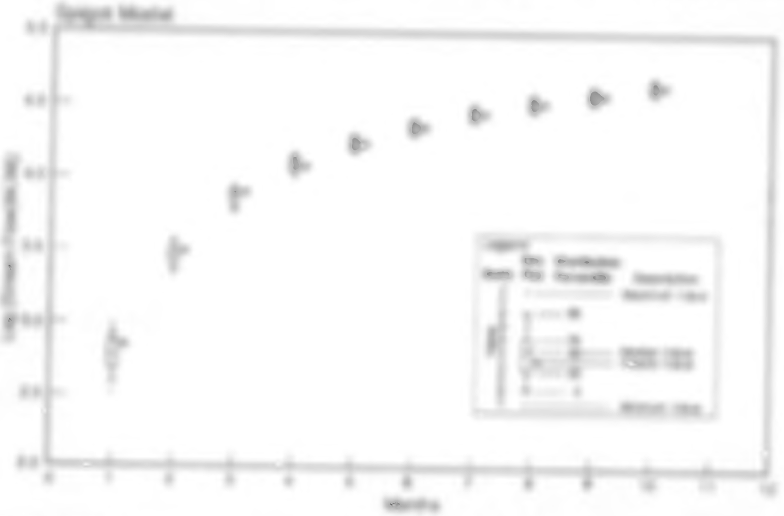


FIGURE 16.2. Evaluation of monthly flow generation models: Run sum comparison

historical characteristics, thereby suggesting that drought occurrences in the historic data also appear in the stochastic sequences.

The storage deficit is the difference between the inflow mass curve and the outflow for assumed withdrawal rates. Percentages up to 80% of the mean annual flow were used as withdrawals. Related statistics are the duration of deficits and reservoir depletion. These statistics were evaluated using Box-plots as described above and illustrated in Figure 16.3. It is evident that the magnitude and deviation of deficits and reservoir depletion are comparable between the historic data and the generated stochastic sequences.

ENERGY BASED MODEL VALIDATION

The second stage validation used system firm and average energy values calculated using a multi-reservoir simulation model. The second stage validation used the *Acres reservoir simulation program* (*ARSP*) model to estimate the system firm and average energy for a series of hypothetical hydroelectric systems in the two test basins.

ARSP is a flexible program designed to simulate multipurpose, multi-reservoir systems. It can represent storage and releases of water by reservoirs; discharge constraints at reservoir outlets, water flow in streams and rivers, power channels, spillways, diversion channels and irrigation canals; agricultural, industrial, municipal or other consumptive demands; hydropower releases; and channel losses. It uses natural inflows, rainfall, evaporation and evapotranspiration as input.

The model was applied using assumed system characteristics over the three reference hydrology periods for each of the models and sequences. Reservoir volumes of 0, 0.5 and 1.0 times the mean annual flow at 3 to 6 reservoirs in each basin. The installed capacity of power stations was also varied to give power flows of 1, 2 and 4 times the mean annual flow. The model was operated with a policy designed to maximize the production of firm energy in the system.

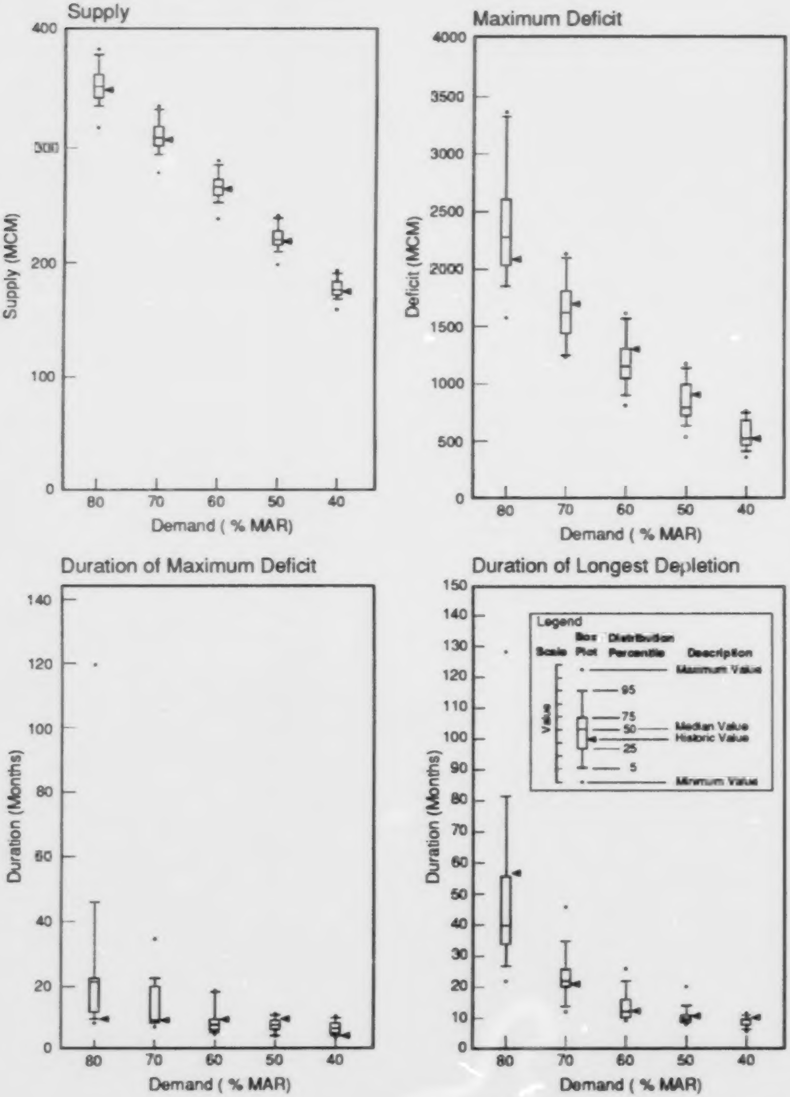


FIGURE 16.3. Evaluation of monthly flow generation models: Deficit analysis

Validation tests consisted of comparison of the cumulative distribution function (CDF) for average energy of the historical sequence to the corresponding CDFs of the generated sequences. Box plots of the firm and average energy were also produced as described for the validation tests. Figure 16.4 shows a comparison of the test results for one of the cases examined.

The difference between the models was not as pronounced in the energy tests as in the streamflow tests. This is a result of the filtering effect of storage on the streamflow sequences. The average energy results still showed a narrow range for the HEC-4 program due to the adjustment of the mean flows. The SPIGOT program produced a somewhat larger range of possibly energy results, but all models generally showed the historical value within the sampling distribution.

Again, the results were consistent between the two basins, indicating the performance of the models is not data specific.

COMPARATIVE ASSESSMENT AND CONCLUSIONS

The study evaluated programs available for stochastic generation of monthly streamflow data for use in design and operations applications. The primary basis for validation of the programs was their ability to reproduce firm and average energy characteristics when used with a multi-reservoir simulation model. Four programs were examined in detail to provide an assessment of how well they reproduce important statistics of the historical streamflow record and basin energy characteristics. The conclusions of the study are based on the use of stochastic hydrology for planning and design applications in hydroelectric power systems. The comparative assessment of the programs is presented in categories of model design, applicability, verification test performance and validation test performance.

The following statements summarize the principle study conclusions.

(1) The SPIGOT program consistently produced streamflow and system energy characteristics which included the historical values within a reasonable sampling distribution. The quality of the generated statistics was similar for the two basins tested, indicating the model

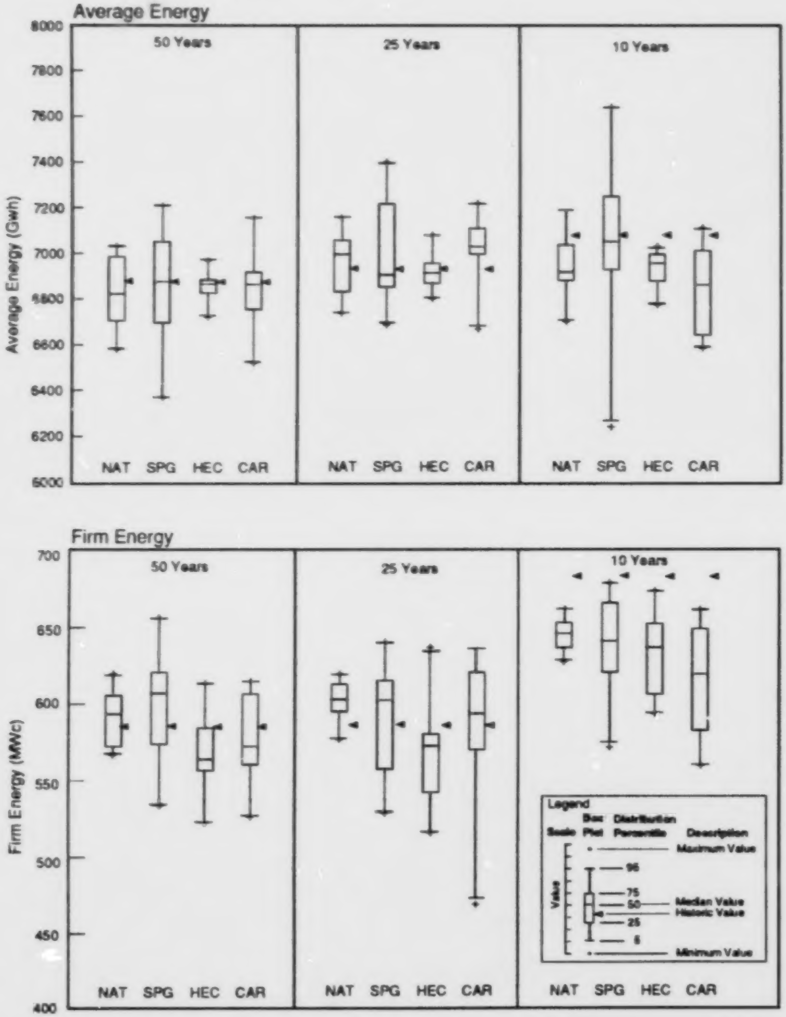


FIGURE 16.4. Evaluation of monthly flow generation models: Average and firm energy

is appropriate over a range of Canadian conditions. The program can be applied after a short familiarization period using the available documentation. The mathematical concepts formulated in the model are theoretically well founded and have been presented and reviewed in the literature.

(2) The NATAL model also consistently produced streamflow and system energy characteristics which included the historical values. The sampling distribution was reasonable and consistent between the two basins. The package is very easy to apply after a short familiarization period.

(3) The HEC-4 program is not recommended for use in streamflow generation studies because of its inability to produce a suitable range of flow data. There was little variability in the moments of the generated data sets. While the program is easy to use, the theoretical basis is now dated and does not reflect recent advances in stochastic hydrology.

(4) CARMA models can be used in design and operations studies. The literature includes several papers describing applications of the models. For this study, an approximate form of the CARMA model was used which did not fully exploit the full potential of the method. Some further research and development work is warranted to prepare a CARMA model in a user friendly environment with supporting documentation. The approach is attractive theoretically because of the ability to easily design parsimonious models specifically for any basin being studied.

(5) The LAST model was not evaluated in detail during this study; however, the theoretical basis for the model has been reviewed in the literature. Some further development work may produce a more complete version of the model for use on a PC environment.

The use of stochastic hydrology methods for hydropower design and operations applications offers several significant benefits such as:

- improving the accuracy of reservoir storage estimates for sites with short streamflow records;

- testing of operating policies under a range of conditions; and
- evaluating the reliability of the system firm yield.

Stochastic streamflow generation methods can be used to estimate the reliability of the system firm yield and the appropriate operating demand on a system of reservoirs. These methods have important applications in long-term planning of system expansions, as well as for short-term operations. With stochastic hydrology, the water manager can make decisions based on probabilistic studies which include uncertainties of hydrology, as well as other factors used in economic risk analysis.

The information presented in this study is intended to encourage and facilitate a broader application of stochastic methods in water resources planning and operations.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the contribution of the Canadian Electrical Association without whose support this study could not have been completed. The valuable contribution of the CEA study monitors Mr. P. Barritt-Flatt of Manitoba Hydro and Mr. P. Bruneau of Hydro Quebec are gratefully acknowledged. Dr. J. Stedinger of Cornell University contributed to the study as an external reviewer, and Dr. J. Grygier provided assistance with model applications. The important contributions of several Acres staff members, including R. Allen, M. Nozdryn-Plotnicki, H. J. Cook, T. Hartung and J. Xiao are also appreciated.

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CHAPTER 17

UNCERTAINTY IN FLOODPLAIN DELINEATION: RECOGNITION, EVALUATION AND REDUCTION

J.D. Paine and W. Edgar Watt

INTRODUCTION

Role of Floodplain Maps in Flood Damage Reduction

Floodplain maps, which delineate the area inundated by a specified flood event, perform two key roles in a flood damage reduction program.

- High quality flood risk maps are the cornerstone of land use restrictions through municipal ordinances such as official plans and zoning bylaws, provincial regulations, and designation pursuant to the federal-provincial flood damage reduction agreements.

- Apart from its role in land use restrictions, flood risk mapping serves at least two other purposes; information on flood risk for the general public, and information on flood damage potential for planners and engineers responsible for determining optimum protection levels or viable flood relief measures.

Since its inception, the National Flood Damage Reduction (FDR) program has funded a large number of flood risk mapping projects and flood studies throughout Canada (Bruce, 1976). Although much of the flood risk mapping in Canada has been completed since 1976 under the FDR program, several maps were completed in the period before 1976 in Ontario (Giles, 1976), British Columbia (Doughty-Davies, 1976), and other western provinces. It is important to note that floodplain mapping encompasses all of the operations involved in producing floodplain maps or in describing areas inundated by the design event. These procedures include hydrological techniques, hydraulic techniques as well as the map production and survey techniques necessary to complete the work.

Uncertainty Defined

Current practice is to prepare the flood risk map product according to specifications. However, it fails to explicitly evaluate the uncertainty associated with the location of the boundaries of the flood risk area which are actual lines on a map where water levels intersect the land surface. The locations of the lines are not known exactly. This lack of exactness is the uncertainty. Figure 17.1 illustrates the uncertainty and shows how uncertainty in water elevation and in ground elevation combine to yield an uncertainty in the depth of inundation and an uncertainty in the width of the floodplain. There is uncertainty associated with each step in the production of a floodplain map (*i.e.*, surveying, mapping, hydrologic studies, and hydraulic studies). It is convenient to classify uncertainty as topographic, hydrologic, and hydraulic referring respectively to determination of elevations of the land surface and water control structures at specified co-ordinates, determination of the design discharge, and determination of corresponding water levels. Obviously, within each of these three categories, there are several separate sources of uncertainty.

Uncertainty is usually expressed in the same units as the variable in question (*e.g.*, m^3/s for hydrologic uncertainty where the variable in question is the design flood expressed in m^3/s) but it may also be expressed as relative uncertainty in percent. However, the primary variable of interest is the location of the floodline (expressed in metres). Hence, each source of uncertainty must be expressed eventually in terms of its contribution to total uncertainty in metres. In this paper, the standard error of estimate of a variable is adopted as an index of the uncertainty of that variable.

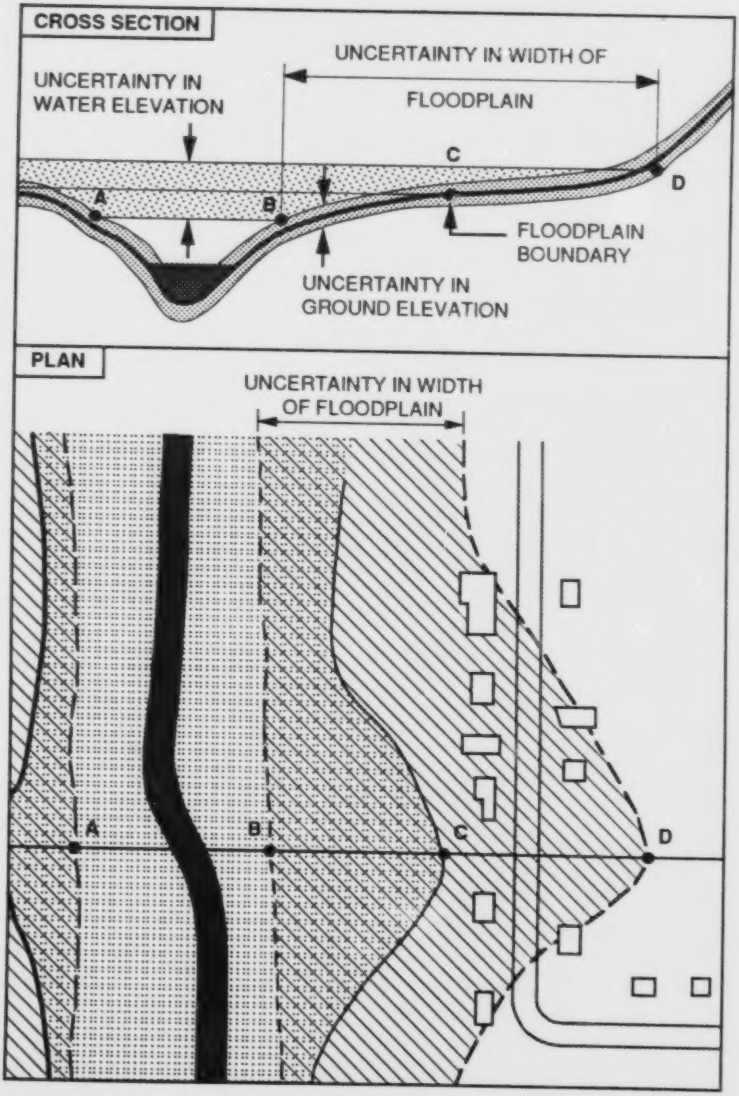
CROSS SECTION
UNCERTAINTY IN WIDTH OF FLOODPLAIN
UNCERTAINTY IN WATER ELEVATION
C
A
B
D
FLOODPLAIN BOUNDARY
UNCERTAINTY IN GROUND ELEVATION
PLAN
UNCERTAINTY IN WIDTH OF FLOODPLAIN
A
B
C
D

FIGURE 17.1. Uncertainty in floodplain delineation

The Need to Recognize, Evaluate and Reduce Uncertainty

The mere recognition of uncertainty by all parties is a first step towards avoiding and resolving conflicts. Evaluation of uncertainty, which follows directly from recognition, leads to the following benefits:

- A more detailed knowledge is provided for assessment of flood risk.
- An additional tool is provided for selecting among a number of design criteria and engineering techniques to maximize the overall quality of mapping for a given project cost.
- Conflicts will be avoided because users are made aware of a difference in map quality arising from differing design flood criteria, availability of hydrometric data, and surveying and mapping methodology even though specifications for producing flood risk maps are identical.
- For small areas, alternative mapping procedures, which until now may have been rejected on a perceived basis of inferior quality, may be shown to be quite acceptable on the basis of uncertainty.
- For large areas, projects which are not feasible in terms of acceptable uncertainty will be identified.

EVALUATION OF UNCERTAINTY

Topographic Uncertainty

Topographic uncertainty manifests itself in two ways. First, river cross sections and longitudinal slopes are required for the hydraulic and hydrologic analyses. These measures can be obtained from topographic maps, digital models from aerial photography, or field surveys in increasing order of precision. This uncertainty in ground surface elevation leads directly to uncertainty in water levels given by the hydraulic model (hydraulic uncertainty) and may lead to uncertainty in flow estimates (hydrologic uncertainty) when a simulation model is used. Second, ground surface elevations are required for determination of the intersections of the water levels corresponding to the design flood with the ground surface. Uncertainty in ground surface elevation leads to uncertainty in the location of these intersections.

Error analysis in the field of topographic mapping is well developed. For example, FDR maps will have been prepared to a specification derived from Class A1 NATO standards that 90 percent of the errors of all contour points will be less than one-half the contour interval (Environment Canada and Ontario MNR, 1985). Based on this specification, the standard error of the elevation of a contour can be shown to be 30 percent of the contour interval or 0.3 m for a map with 1 m contours.

The uncertainty in ground surface elevation can be reduced through the use of field surveys to determine cross sections in conjunction with existing mapping or as an independent means of defining the ground surface elevation. Vertical and horizontal errors depend on the method of field survey techniques used. Methods from most to least precise include: (1) theodolite and electronic distance measuring equipment, (2) chain and level, and (3) stadia surveying. Given the small areas or reach lengths normally involved, and provided closed circuits are run, the standard error of vertical measurement is small for each of the field survey techniques and is estimated to be about 10 percent of the contour interval.

Hydrologic Uncertainty/Flood Frequency Analysis Techniques

Hydrologic uncertainty is defined herein as the standard error of the design discharge and in SI is expressed in m^3/s. In two special cases, the hydrologic uncertainty is zero:

(1) when the floodplain is delineated by a specified water level; and

(2) when the floodplain is delineated by the water level corresponding to a specified flow.

When the design discharge is determined by single site frequency analysis techniques, the uncertainty results from a lack of knowledge of the 'true' distribution and the sampling error. Recent studies indicate that the relative standard error in the 100-year flood estimate due to the first source of uncertainty is about 5 percent (Chow, 1988). The sampling error varies inversely as the square root of the period of record, N. For long-term Canadian hydrometric stations, the sampling error is about $65/\sqrt{N}$ (Watt and Paine, 1992) so that the relative standard error of the 100-year flood (in percent) can be approximated by 5+ as $65/\sqrt{N}$.

For rivers with short or non-existent records, the design discharge must be obtained from a regional analysis. The results of regional analyses indicate that the relative standard errors of the 100-year flood estimate for an ungauged site are about 25 percent (Moin and Shaw, 1985; 1986). For rivers with neither very short nor very long records, some combination of single site and regional estimates should be used to minimize the statistical uncertainty.

Hydrologic Uncertainty/Streamflow Simulation Techniques

When the design discharge is determined by streamflow simulation techniques, the uncertainty results from input uncertainty and modelling uncertainty. Rainfall inputs are normally determined by frequency analysis and hence, as for floods, the uncertainty in depth of rainfall, is due to distribution uncertainty and sampling error. For the 100-year rainfall, the input uncertainty is about 20 percent (Watt and Paine, 1992). For rain plus melt inputs, the uncertainties in the snowmelt model and the critical temperature sequence must be added. In this case, the resulting input uncertainty is about 30 percent. A particular case should be noted. The Regional Storm criterion in Ontario is a very large specified rainfall input. Although the hyetographs are based on recorded rainfalls (Hurricane Hazel and the Timmins Rain), zero input uncertainty is implied.

Modelling uncertainty can be classified as model uncertainty (*i.e.*, how well does the conceptual model represent the prototype hydrologic system) and parameter uncertainty (*i.e.*, how accurate are the values of the model coefficients). Most event models comprise two principal submodels: a loss or abstractions model and a routing model. In many applications, the event model is quasi-distributed in an attempt to represent the prototype system. Unfortunately, because of a lack of data for calibration, this attempt to reduce model uncertainty results in an increase in parameter uncertainty and may actually increase overall modelling uncertainty. Of the two submodels, the loss model usually introduces more uncertainty than the routing model even when the modeller is very experienced. Although modelling uncertainty varies from application to application, the two dominant factors affecting it are the magnitude of the input (larger inputs lead to increased uncertainty) and whether or not calibration is realized. For a large specified input such as the 100-year rain and no calibration, the modelling uncertainty might be of the order of 45 percent. With reliable calibration, the modelling uncertainty might be 20 percent although 30 percent is thought to be a more typical value. Input and modelling uncertainty can be combined by simple vector addition if the two sources are independent. For the case of the Regional Storm, the input uncertainty is zero. However, the modelling uncertainty is very large because of the magnitude of the input and the fact that calibration is not possible. It has been estimated at 50 percent. Hydrologic uncertainty for various design flood criteria is displayed in Figure 17.2.

Hydraulic Uncertainty

Hydraulic uncertainty is defined herein as the standard error in the depth of flow resulting from uncertainties in the hydraulic model; in SI, it is expressed in metres. In the present context, hydraulic uncertainty may be considered to arise from two sources, model uncertainty and parameter uncertainty.

Model uncertainty is due to the inaccurate representation of the flow mechanisms by the analytical technique applied. Except for complex situations, such as confluences, two-dimensional flows, split flow and presence of ice, the state-of-the-art is relatively well developed. Normally, appropriate and accurate techniques can be selected and applied. However, different computer programs to apply these techniques differ slightly in their computation procedures. The result is that even with identical data, substantial differences in flood elevation can arise depending on the backwater program used. In a comparison study, Dawdy and Motayed (1978) concluded that there was an uncertainty of about 4 percent of maximum depth which could not be eliminated because there were no means to judge among the various programs. This 4 percent should be considered a minimum. In most practical applications, there is an additional uncertainty due to the fact that the model does not represent the prototype situation. This deficiency is particularly true in areas of expanding and contracting flow, where there is significant conveyance on the floodplains. In the absence of published data, this additional uncertainty is estimated at

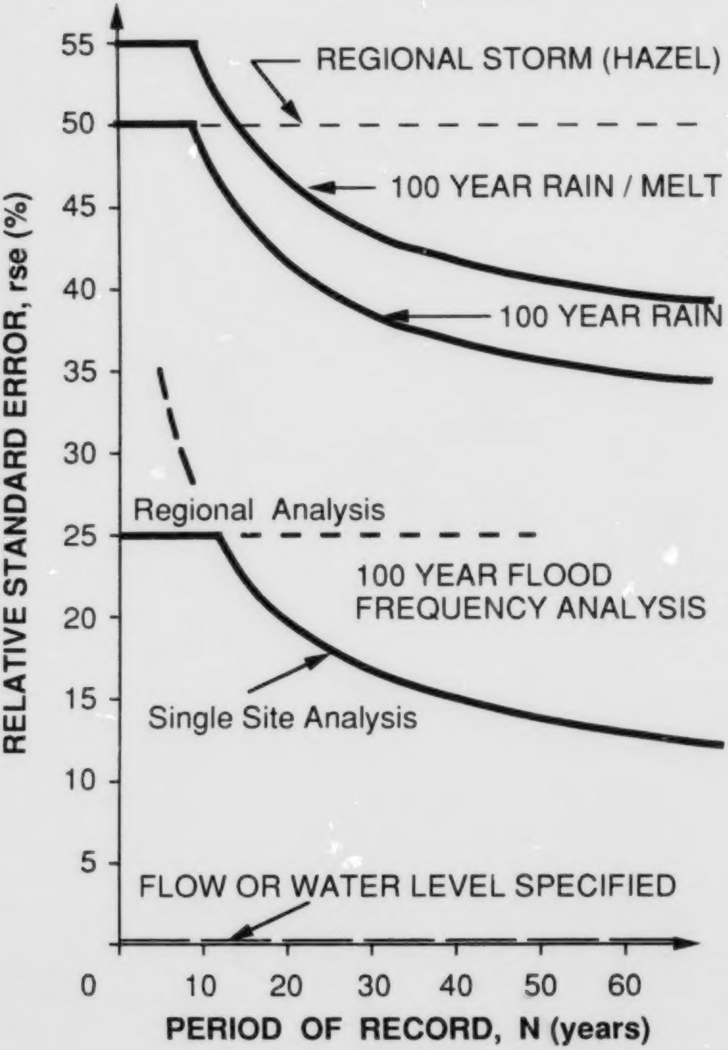

FIGURE 17.2. Hydrologic uncertainty for various design flood criteria

5 percent for applications without calibration. This uncertainty can be effectively eliminated through comprehensive calibration.

Uncertainty also results from inaccurate representation of the systems geometry in the model being applied. In this case, it can be reduced by obtaining in a selective manner more survey data and increasing the spatial resolution in the model. There is little published information on the magnitude of this uncertainty but it appears that section selection and spacing by a competent hydrotechnical engineer results in uncertainties that are small compared to hydraulic uncertainties arising from other sources.

Parameter uncertainty occurs when there are insufficient data with which to calibrate or when calibration is not undertaken. Ideally, the model should be calibrated for flow magnitudes similar to the design event, and split sampling should be used to verify the calibration achieved. The best-known parameter is Manning's n. According to Dawdy and Motayed (1978), "the errors in estimation of Manning's n used to solve the equations of flow are unknown. However, they can easily be of the order of 20 percent (*e.g.*, 0.025 ± 0.005). The usual method of estimation of Manning's coefficient is subjective and visual." The resulting uncertainty in flow depth will vary from site to site but based on tests by Dawdy and Motayed (1978) a value of 5 percent of the flow depth would appear to be reasonable. Hydraulic uncertainty arising from this source can be reduced significantly through calibration. Other parameters include expansion and contraction coefficients, and bridge coefficients. The relative importance of this source of uncertainty compared to that introduced by Manning's n depends on the regime of the river and the magnitude of form losses compared to friction losses. Where form losses govern, it is suggested that the resulting uncertainty in flow depth would be at least 10 percent. Even more than in the friction case, hydraulic uncertainty can be reduced significantly through calibration.

Water Surface Elevation (Depth) Uncertainty

In most cases, the hydrologic and the hydraulic uncertainties are essentially independent and may be combined to produce an estimate of the total uncertainty of the flow depth. Exceptions to this independence occur when the hydrologic uncertainty arises from use of a simulation model (as opposed to frequency analysis) and the modelled flow is affected significantly by the same hydraulic components as those used in the hydraulic model. Such significant effects are believed to be rare.

Contribution due to hydrologic uncertainty

This element refers to the uncertainty in depth of flow resulting from a given hydrologic uncertainty (assuming a 'perfect' hydraulic model). Watt and Paine (1992) show that the uncertainty in depth of flow, as expressed by $se(y)_1$, is related to the hydrologic uncertainty through the rating curve at the location of interest which depends on the type of control (*i.e.*, friction, structure, combined) and the geometry and parameters of the control section.

$$se(y)_1 = \beta y \; rse\,(Q) \qquad [1]$$

Here β is the exponent for a power function fit to the rating curve (for a broad channel, $\beta = 3/5$ and for a broad-crested weir or rock sill where $\beta = 2/3$). For example, consider the case where the rse (Q) = 50% (uncalibrated hydrologic model, regional storm specification), the depth of flow is 2.0 m and there is friction control in a wide channel. From eqn. [1], the uncertainty in flow depth is 0.6 x 2.0 x 0.5 = 0.60 m or twice the topographic uncertainty for FDR mapping with a 1 metre contour interval.

Contribution due to hydraulic uncertainty

The uncertainty in depth of flow due to uncertainty in the hydraulic model, $se(y)_2$, has been shown to range from 5 to 19 percent of the depth. This relative uncertainty (rse) is converted to absolute uncertainty through

$$se(y)_2 = rse(y) \cdot y \qquad [2]$$

Uncertainty in Depth of Inundation

The depth of inundation is simply the difference (if positive) between the elevation of the water surface, (z_w), and the elevation of the ground surface, (z_g),

$$
\begin{aligned}
d &= z_w - z_g && \text{if } z_w > z_g \\
y &= 0 && \text{if } z_w \le z_g
\end{aligned}
$$

Because water surface elevation uncertainty and topographic uncertainty are independent, the uncertainty in d is

$$
\begin{aligned}
se(d) &= [se(z_w)^2 + se(z_g)^2]^{1/2} \\
&= [se(y)^2 + se(z_g)^2]^{1/2} \qquad [3]
\end{aligned}
$$

CONTROL OF UNCERTAINTY

Total Uncertainty and Map Use

The uncertainty in depth of inundation should dictate the use(s) of the flood risk map which ranges from the basis for land use restrictions through public information to preliminary planning. Suggested guidelines for matching total uncertainty to map use, presented in Paine and Watt (1992) are based on a maximum uncertainty in depth of inundation as twice the standard error of the contour interval which would be suitable for the map use. For example, FDR maps with a typical contour interval (standard error = 0.3 m) would have a maximum uncertainty of 0.6 m. Corresponding uncertainties for maps for municipal zoning and official plans (standard error = 0.6 m) and maps for preliminary planning and design (standard error = 0.9 m) would be 1.2 and 1.8 m respectively.

The use of a more accurate map than required may imply unnecessary expenditures in terms of time and budget. The use of a less accurate map than required may have serious consequences. Inaccurate location of a floodline could lead to legal challenges, and could create unwarranted hardships for individual property owners.

Compatibility of Water Surface and Topographic Uncertainties

As shown above, the uncertainty in water surface elevation (hydrological and hydraulic analyses) and the uncertainty in ground surface elevation (surveying and mapping) contribute with equal weighting to the uncertainty in the flood depths and the associated location of the floodline.

These two uncertainties should be approximately equal if the objective is to minimize the total cost required to achieve a specified uncertainty in depth (or vice-versa). The ratio of the two uncertainties for optimum mapping will vary within a map sheet and from project to project but in general, should be in the range 0.5 to 2.

This range of compatibility of the topographical mapping and the hydrologic/hydraulic engineering components for flood risk map production is displayed in Figure 17.3 as a shaded zone. In this figure, contours of total uncertainty are arcs of a circle. The area between two adjacent arcs represents the optimal 'uncertainty level' for the specified use. Where such an area intersects the zone of compatible uncertainty (shaded), the mapping is both optimal and compatible (*e.g.*, hatched area for use 6). The area above the zone of compatible uncertainty represents situations in which good topographic mapping exists but excessive uncertainty in the water surface represents an unbalanced project. The area below the shaded zone represents situations where the mapping is of inadequate precision for the best possible product.

Compatibility is desirable for a number of reasons, including economics, and the desire not to mislead the user into attaching undue confidence in the result. For example, very precise maps used in conjunction with an uncalibrated design input may not only represent a needless expenditure on map production but also may tend to convey the impression that the accuracy in the placement of the floodline is the same as the precision of the maps. However, incompatible uncertainties could be justified where:

- a more precise base map is used because it exists;
- more precise maps are produced to cover the eventuality that additional future data will permit calibration of the hydrologic or hydraulic models; and
- a less precise map is used because of an urgent need for planning information.

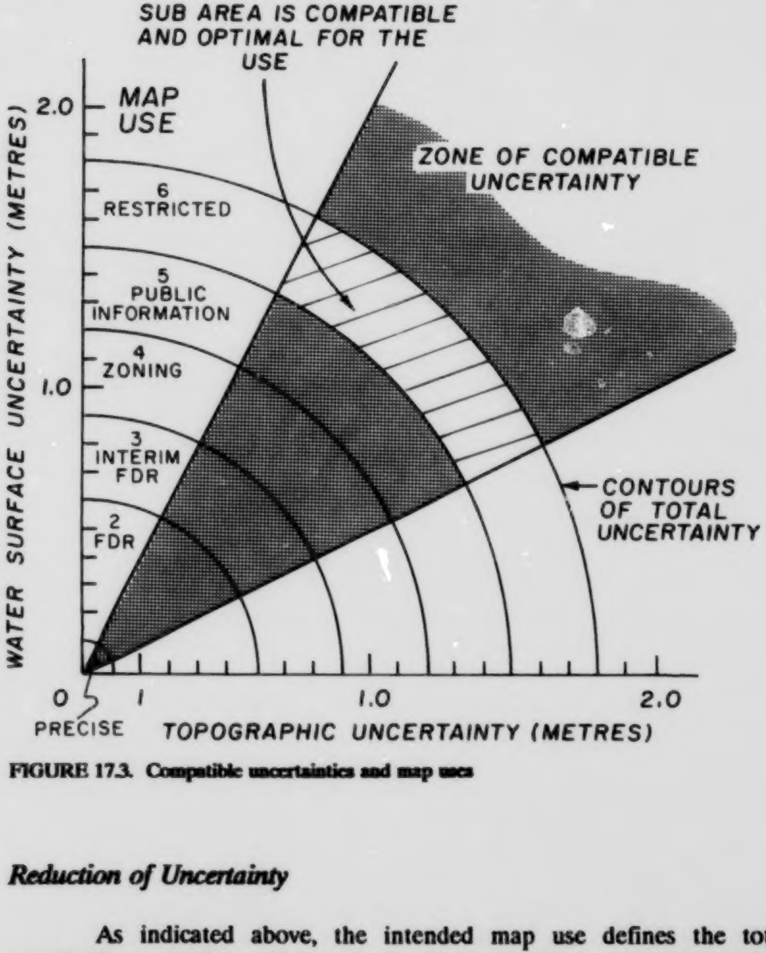

FIGURE 17.3. Compatible uncertainties and map uses

Reduction of Uncertainty

As indicated above, the intended map use defines the total acceptable uncertainty and the concept of compatible uncertainties further restricts the two components to a particular range. If, for a particular project, the uncertainties do not exceed these limits (*i.e.*, the mapping is both compatible and optimal - see Figure 17.3) there is no need to reduce uncertainty.

However, in some cases a reduction in either or both water surface and topographic uncertainty will be necessary. Consider first a reduction in topographic uncertainty. For new projects, this can be accomplished by more stringent specifications on the contour interval or the selection of alternative procedures such as detailed field surveys. For existing mapping, the topographic uncertainty in particular areas can be reduced by detailed field surveys.

Water surface uncertainty usually exceeds topographic uncertainty. The main opportunity for reducing water surface uncertainty is by changing the criterion for the design flood to one yielding smaller hydrologic uncertainty. This adjustment will not only reduce the contribution due to hydrologic uncertainty (see Figure 17.2) but may also reduce the contribution due to hydraulic uncertainty because calibration of the hydraulic model may now be possible.

SUMMARY

1. Flood risk areas are defined as those areas inundated by the design flood event, that is the water surface elevation exceeds the ground surface elevation. Uncertainty in specifying this area results from uncertainties in determining these two elevations.

2. Both the uncertainty in ground surface elevation and the uncertainty in water surface elevation are quantifiable; for convenience, they can be expressed as a standard error in metres. The uncertainty in ground surface elevation determined from photogrammetrically-derived maps varies directly with the contour interval. The corresponding uncertainty for maps derived from field surveys alone is considerably lower. The uncertainty in water surface elevation depends on the reliability of the calibration of the hydrologic and hydraulic models.

3. In general, the two uncertainties (ground elevation and water elevation) should be similar in magnitude (compatible) and the total uncertainty in depth of inundation, which is equal to the vector sum of these two uncertainties, should dictate the use of the map.

4. Recognition, evaluation and reduction of uncertainties results in economic and social benefits.

ACKNOWLEDGEMENTS

The work on which this paper is based was carried out by contract under the Canada/Ontario Flood Damage Reduction Program. The assistance of those members of the Technical Sub-Committee who formed the project administration team is gratefully acknowledged.

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CHAPTER 18

PHYSICALLY-BASED ESTIMATES OF FLOOD PROBABILITIES

Ivan Muzik and Chiadih Chang

INTRODUCTION

Flood estimates are required for the design and economic appraisal of a variety of engineering works, including dam spillways, bridges and flood protection works. Much effort has been devoted to developing statistical methods of predicting flood peaks. Limitations of probabilistic and other operational models (*e.g.*, regression relation, polynomial fit and a transfer function) have been discussed by Klemes (1982). The major limitations are:

(1) an operational model is nothing more than 'geometrical' interpolation formula and will give best results in the range where the amount of empirical evidence is largest.

(2) There is no reason inherent in the mathematical structure of the model why it should be valid outside the range of data to which it has been fitted.

(3) The improvement of an operational model requires either more empirical data or more casual input, (*i.e.*, more information on the phenomenon being modelled). It cannot be achieved merely by more mathematics.

These issues suggest that further development of such operational models is not possible until more empirical data becomes available. Rather than waiting hundreds of years before 'more' data is recorded, some hydrologists have developed physically-based stochastic models of the hydrologic cycle. Eagleson (1972) was among the first to pioneer this approach. He derived the peak discharge distribution from a given distribution of rainfall by means of a kinematic wave catchment model. However, complicated mathematical manipulations rendered the model impracticable for operational use.

This paper describes a physically-based stochastic model of the rainfall-runoff process using a modified Soil Conservation Service (SCS, 1972) method for abstractions. Together with a dimensionless unit hydrograph, the model is applied in a Monte Carlo simulation to derive a synthetic flood frequency curve for a watershed from a given stochastic rainfall input. The usefulness of this approach in significantly reducing uncertainty is provided through use of a case study.

RUNOFF PREDICTION

Application of the unit hydrograph method for prediction of a flood hydrograph requires the determination of excess rainfall. Excess rainfall is that part of the observed total rainfall which is neither retained on the land surface nor infiltrated into the soil. Assuming Hortonian overland flow (Chow *et al.*, 1988), excess rainfall becomes direct runoff at the watershed outlet. The difference between the observed total rainfall and the excess rainfall is called abstractions. Abstractions include interception (*i.e.*, precipitation caught and retained on vegetation above the ground), and infiltration of water into the soil. Usually, interception and depression storage are combined and termed the initial abstraction.

Various approaches exist for determining the rate of abstractions from rainfall. In this paper, the Soil Conservation Service (1972) method for calculating abstractions has been adopted. The method, known as the runoff curve number method, has been modified to take into account stochastic properties of abstractions.

Standard SCS Method

The Soil Conservation Service (1972) procedure for computing abstractions from storm rainfall relates the depth of excess rainfall or direct runoff (P_e) to the total rainfall depth (P), initial abstraction (I_a) and potential maximum retention (S) by the following equation:

$$P_e = \frac{(P - I_a)^2}{P - I_a + S} \qquad [1]$$

An empirical relation was developed by the Soil Conservation Service (1972):

$$I_a = 0.2\ S \qquad [2]$$

which after substitution into eqn. [1] yields

$$P_e = \frac{(P - 0.2\ S)^2}{P + 0.8\ S} \qquad [3]$$

The potential maximum retention (S) is assumed to depend on soil type, land use and land cover. It is high for deep sandy soils and low for shallow clayish soils. For convenience, the potential maximum retention (S) is converted into a parameter having the range of values between 0 and 100

$$CN = \frac{1000}{S + 10} \qquad [4]$$

The parameter CN, called the curve number, is equal to zero when there is no direct runoff generated. The value of 100 on the other hand means no abstractions and the depth of excess rainfall equals the depth of total rainfall. Curve numbers have been tabulated by the Soil Conservation Service (National Engineering Handbook, Section 4, 1972) on the basis of soil type and land use for three antecedent moisture conditions. Since the method is relatively simple, requires readily available information, and considers a few physically-relevant parameters (*e.g.*, soil type, land use, land cover), the SCS method for calculating abstractions has gained wide acceptance among hydrologists in North America.

Modified SCS Method

The runoff curve method was developed primarily for design applications in catchments which are not gauged. The standard tables provide helpful guidelines, but estimation of runoff curve numbers directly from local or regional data is recommended for increased accuracy (Ponce, 1989). Furthermore, the maximum potential retention (S) and initial abstraction (I_a) are in fact variables rather than constants. The following is an outline of a modified SCS procedure which was developed by the authors for use with local rainfall-runoff data, and which takes into account the stochastic character of parameters S and I_a.

The modified SCS method was tested using data from 55 watersheds located in Alberta foothills, stretching from Montana border in the south to as far north as the town of Rocky Mountain House. The topography of the area ranges from rugged, barren mountain ridges, to the west to rolling forested foothills in the east. Land cover is predominantly coniferous or mixed forest. Exceptions to these are areas of exposed bedrock along the higher mountain ridges and deciduous treed grassland areas at the lower elevations. Surface geology is comprised mainly of glacial moraine and colluvium. Bedrock geology includes shales, sandstones and limestone. According to the SCS classification, soils in the area generally fall into the B or C hydrologic soil group. Runoff curve numbers, determined from standard SCS tables and for antecedent moisture condition II, range from 65 to 85.

Modifications to the standard SCS method are presented in Figure 18.1. This modified method recognizes the stochastic behaviour of S and I_a. Analysis of rainfall-runoff data in the study region showed the existence of a general relationship between the maximum potential retention (S) and the amount of rainfall accumulated within the five days prior to runoff in question. The five day antecedent rainfall, (P5), has been found to be a random variable having a log-Pearson type III probability distribution. In recognition of this dependency of S on P5, the maximum potential retention (S) is designated to be the dependent stochastic variable.

The initial abstraction, (I_a), is assumed to be a purely random stochastic variable. Chang and Muzik (1991) demonstrated that the probability distribution of I_a can be well approximated by log-Pearson type III distribution.

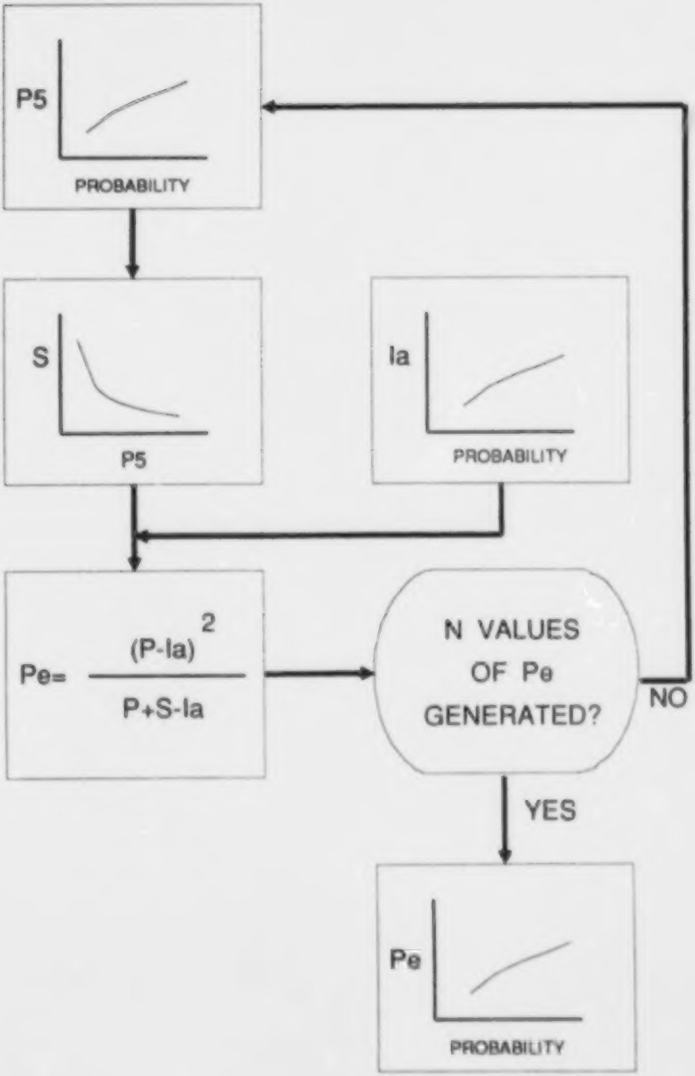
P5
PROBABILITY
S
P5
Ia
PROBABILITY
Pe= (P-Ia)^2 / P+S-Ia
N VALUES OF Pe GENERATED?
NO
YES
Pe
PROBABILITY

FIGURE 18.1. Generation of excess rainfall probability distribution by Monte Carlo simulation with the modified SCS method

In summary, by replacing the deterministic relationships among S, P5 and I_a with stochastic relationships, the modified SCS method yields a probability distribution of excess rainfall (P_e) for given total rainfall (P), rather than a single values of P_e as predicted by the standard SCS method. This procedure significantly reduces the uncertainty associated with the return period of the peak discharge computed from excess rainfall because the probability of occurrence of excess rainfall and the corresponding peak discharge may be assumed, within certain limits, to be the same.

GENERATION OF PEAK DISCHARGE

Flood hydrographs were simulated in the present study by means of hydrologic modelling software supported by a geographic information system (GIS). The hydrologic model employed by this software treats a watershed as a lumped system. Excess rainfall is converted into direct runoff by convolution with a synthetic unit hydrograph which is derived by means of a regional dimensionless unit hydrograph and a regional lag-time relationship. Details of the software and procedure are found in Muzik and Pomeroy (1990), and Chang and Muzik (1991).

Monte Carlo Simulation

The Monte Carlo method is essentially an experimental statistical method of generating long series of a variable of interest in order to solve some probability problem associated with the variable. A typical example is the calculation of the safe water yield for a reservoir. A large number of reservoir inflows can be obtained by the data generation method, and the frequency distribution of safe yield as a variable can be computed.

In the present study, the Monte Carlo method is used to generate a large number of independent values of peak discharge in order to estimate its probability distribution function. Peak discharge values are generated by transforming randomly drawn values of total rainfall (P) from its known probability distribution into flood hydrographs. The transformation, or the simulation model, has both deterministic and stochastic components. The stochastic component generates random values of P_e basically by the process illustrated in Figure 18.1 to which the generation of random P values is added. The steps in this process are as follows:

(1) generate a random value of the five-day antecedent precipitation [P5];

(2) given P5, obtain the maximum potential retention [S];

(3) generate a random value of the initial abstraction [I_a];

(4) generate a random value of total rainfall [P] (see example for details); and

(5) compute the excess rainfall depth [P_e].

The excess rainfall (P_e) is then transformed deterministically, by means of the unit hydrograph method, into a flood hydrograph. Repetition of this procedure N times (where N is of the order of thousands) provides a large sample for determination of the derived distribution, or the synthetic frequency curve, of peak discharge.

In summary, the described mechanism for generating the synthetic flood frequency curves is based on a physical model of runoff whose parameters (S, P5, I_a) are considered to be stochastic variables having certain probability distributions. This approach allows one to combine the knowledge of physics with the theory of probability. In other words, by studying basic physical processes we are likely to put reasonable limits on such parameters as S and I_a. This physically-based confidence in certain parts of the Monte Carlo generation process eventually results in an increased confidence with respect to the final product of the simulation (*i.e.*, the predicted flood magnitudes and their probabilities).

CASE STUDY

The Little Red Deer River watershed was used to illustrate the usefulness of utilizing the synthetic flood frequency curves to calculate flow. Little Red Deer River near Water Valley - Station No. 05CB002 has a drainage area of 451 km^2 and 24 year long record of natural flow.

The first stage of the simulation is to digitize the watershed boundary and the main watercourse using a 1:50,000 scale topographical map. The digitized values are input into the GIS-hydrologic software package. The software is menu driven and performs the steps involved in the Monte Carlo simulation as described previously. The total rainfall amount (P) was chosen randomly for each run from the Gumbel distribution of P. Parameters of the distribution appropriate for the study watershed were determined automatically by the GIS which stored depth-duration data and parameters of the associated Gumbel distributions published in the *Rainfall Frequency Atlas of Canada* (1985).

The Monte Carlo simulation generated 6,000 values of peak discharge. This distribution is plotted in Figure 18.2 as a dotted line. Also shown in the figure are 24 observed peak flows and the fitted log-Pearson type III distribution (solid line). The Chi-square goodness of fit test indicates that both the log-Pearson type III distribution and the generated

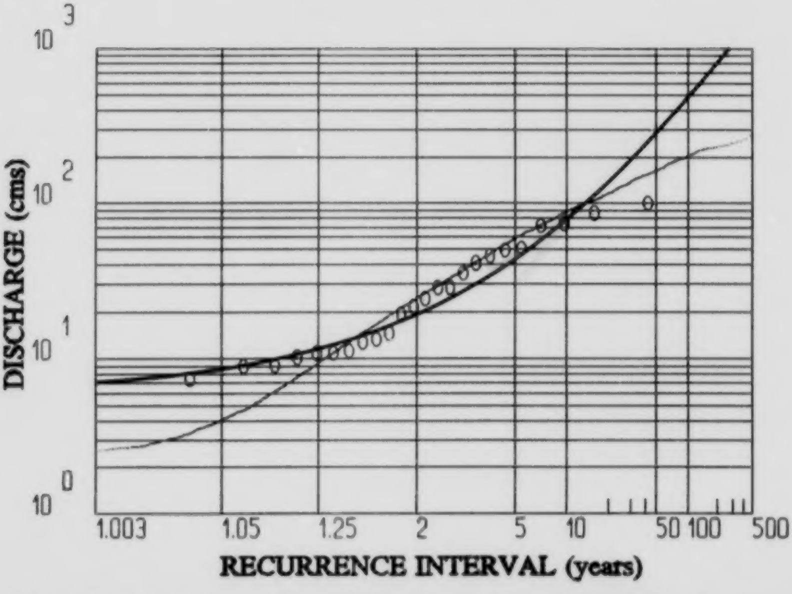

FIGURE 18.2. Little Red Deer River empirical frequency curve compared to fitted log-Pearson III distribution and derived distribution

synthetic distribution have an acceptable fit. However, the two distributions differ significantly in their tail sections. While the log-Pearson III or any other fitted probability distribution is either accepted or rejected as is, the described technique of derived distributions allows one to reexamine critically both deterministic and stochastic components of the simulation model. This review, supported by usual statistical tests, allows one to determine the validity of the generated distribution, or to modify some of the relationships.

CONCLUSIONS

Estimation of extreme flood flows is generally a very difficult task because of the complexity of flood generating processes. Two main approaches have been used in the past. The first is based on statistical analysis of flood series, and the second on investigation of rainfall and resulting runoff. The present study combined both of these techniques in a Monte Carlo simulation resulting in a derived (synthetic) distribution of flood flows. The method has been tested in a study region along the eastern slopes of Rocky Mountains with the aid of a hydrologically-oriented GIS. Based on results of this study, three conclusions are made. First, the standard SCS method generally leads to underestimation of the amount of direct runoff in Alberta foothills. Second, the modified SCS method improves runoff predictions because of superior relationships for S and I_a derived from local data. Finally, physically-based stochastic rainfall-runoff models show a strong potential in deriving synthetic flood frequency curves. The distinct advantage of this approach over statistically fitted probability distributions to observed flood flows is its ability to assess the consequences of various inputs. Thus, even if the 'true' distribution of rainfall input, maximum potential retention, initial abstraction, and other variables are not exactly known, effects of their variation within physically reasonable limits can be assessed, and considered in water resources planning and design.

ACKNOWLEDGEMENTS

This work has been supported by a research grant from the Natural Sciences and Engineering Research Council of Canada.

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Economic Instruments

CHAPTER 19

EFFICIENT MUNICIPAL WATER UTILITY OPERATIONS UNDER DEMAND UNCERTAINTY

Steven Renzetti

INTRODUCTION

There has recently been a significant increase in the attention paid to water pricing in Canada (*e.g.*, Pearse, Bertrand and MacLaren, 1985; Tate, 1989; Renzetti, 1992). Much of the motivation for this work has been the perception that the way in which water prices are set is incorrect and that water prices are too low in some sense. In seeking out alternative water pricing rules, most researchers have drawn upon the extensive economics literature concerned with optimal public sector pricing. This type of analysis has resulted in calls for water utilities to move to efficient pricing rules such as marginal cost pricing and peak-load pricing.

There are at least two problems with these proposals. First, there is scant real-world evidence that reforming water prices will lead to the conservation of water resources or will improve the welfare of water users although Renzetti (1992) is an exception. Second, the economic models that have been used to criticise water utility practices frequently neglect important features of utility operations. For example, the presence of demand uncertainty and its impact on the operations and pricing behaviour of water utilities has received only limited attention (Crew and Kleindorfer, 1986).

This paper addresses the second of these problems. Thus, its first task is to argue that the criticisms levelled in the past against the pricing and investment decisions of municipal water utilities also hold when one accounts for the presence of demand uncertainty. The second task is to illustrate how economic models may be used to generate efficient pricing and capacity expansion rules that incorporate demand uncertainty. In this context, efficient prices are those which lead consumers to choose consumption levels that maximize the social net benefits associated with water use.

The remainder of the paper is divided into three sections. First, the economic criticisms of water utility operations in both certain and uncertain environments are outlined. This review is followed by a brief intuitive description of the results of a model which derives efficient prices and capacity for a water utility facing demand uncertainty. More formal presentations of this class of theoretical models are available elsewhere (Crew and Kleindorfer, 1986; Rees, 1984). Finally, the implications for water management are presented.

EVALUATION OF WATER UTILITY PRACTICES

In this section, the practices followed by most North American water utilities are critically assessed. The guidelines for many of these practices can be found in the American Water Works Association's *Water Rates Manual* (1983). This analysis is conducted in two stages. The first reviews the general rules used by these utilities to set price and capacity. The second addresses the specific issue of how these agencies cope with the presence of demand uncertainty.

Practice of Pricing and Capacity Determination

The cost accounting and pricing activities of water utilities have drawn criticisms from several authors (Hirshleifer, DeHaven and Milliman, 1960; Martin *et al.*, 1984; Pearse, Bertrand and MacLaren, 1985; Tate, 1989; Renzetti, 1992). The arguments supporting those criticisms are summarized here.

A utility first establishes an estimate for its projected annual expenditures (based on a forecasted level of output that is derived by applying an exogenously determined growth rate to last period's output). Projected expenditures are the sum of expenditures on operations, scheduled maintenance activities and debt-retirement costs. With respect to obtaining raw water supplies, Canadian municipal water utilities pay for their raw water only if they obtain it from a regional wholesaler or if they are located in one of the provinces which charges a royalty on direct withdrawals of surface water. These provinces are British Columbia, Saskatchewan and Nova Scotia. Expenditures related to system expansion are usually funded separately, not from current revenues but from issues of new debentures.

The implication of these practices for water prices can be summarized. All water prices are based on the utility's estimated average cost of supply. Residential consumers typically face either an annual connection fee for service, or a combination of an annual fee and a constant unit price if consumption is metered. Commercial, institutional and industrial consumers usually face an annual fee and a price schedule characterized by declining marginal prices. The principal reason for these price differences is the way that utilities allocate their capital costs across user groups.

Water utilities choose a network configuration and capacity level that allows them to meet exogenously specified performance requirements at minimum cost to the utility (Morgan and Goulter, 1985). These requirements typically include pressure levels which allow the utility to meet fire-fighting needs while still servicing the needs of households and businesses.

There are several reasons why water prices are inefficient. Annual recorded expenditures are unlikely to equal the full economic costs of service. This approach is used because water is typically assigned no value unless it is purchased from a regional wholesaler. If the municipal utility does not pay for its water, its output price will reflect the costs of collecting, storing and treating water, but not the value of the resource itself.

The use of average cost as a basis for water prices is significant for several reasons. Efficiency requires that consumers know what new costs are imposed on society each time they choose to consume water. In most cases, the average cost will not tell them this because it reflects the past decisions of the utility rather than the future actions which must be undertaken because of the consumer's consumption choice. In addition, the use of average cost as a basis for pricing may mean that prices do not reflect the costs of consumption decisions because the utility calculates each user group's average cost using an arbitrary method of allocating joint capital costs across user classes.

Water prices frequently differ across user groups. However, there is little evidence that these price differences reflect accurately the costs of serving different user groups. Furthermore, water utilities have neglected to differentiate prices according to the distance of a consumer from the supply centre or according to when consumption takes place.

There are also several reasons why the chosen level of capacity is likely to be inefficient. First, utilities' accounting procedures lead them to undervalue current capital costs and this encourages over-capitalization. Annual capital costs are measured as the expenditures needed to retire any debt incurred for past system construction rather than the current period's cost of expansion. If capacity expansion costs are rising over time, then the fact that the current costs of system expansion are not incorporated into the current period's prices implies that the latter will understate the full costs of consumption. Thus, utilities' pricing practices lead them to over-estimate demands and, thus, over-capitalize.

Second, consumer demands are seen by utility planners as exogenously determined needs or requirements and, as a result, there is no attempt made to maximize the benefits to society through the appropriate choice of capacity. Since consumer demands are considered exogenous, no attempt is made to measure the market's valuation of increments to capacity. Without this information, it is difficult to see how decision making will yield the socially-preferred level of capacity.

Water Utility Operations Under Uncertainty

The presence of demand uncertainty influences the behaviour of water utilities in several ways. First, the utility's storage and delivery capacity is designed to supply a quantity of water that represents the utility's forecasted requirements plus an exogenously chosen margin to meet unexpected needs. In this situation, however, the utility's definition of water requirements is described by the exogenously set pressure levels and flow rates that must be provided rather than the economist's notion of a desired level of consumption at a given price. An alternative way to interpret the utility's choice of capacity is to see the utility as also choosing a level of service reliability (*e.g.*, having no greater than a 5% probability of demand exceeding capacity in any 24-hour period).

Second, the utility sets in place a rationing scheme that is to be used should demand threaten to exceed capacity. This scheme typically takes the form of a set of administrative rules to reduce or prohibit certain types of consumption. For example, lawn watering may be banned or allowed only during specific periods. It is important to note that the setting of water prices is not directly influenced by the presence of demand uncertainty. Thus, prices do not act to ration scarce water supplies nor is the level of water prices allowed to fluctuate to signal changes in the relative scarcity of water.

These responses to the presence of demand uncertainty are unlikely to lead to the efficient allocation of water resources. The capacity level is unlikely to be efficient because it is chosen to satisfy some exogenously set level of service reliability. There is little reason to expect that this standard is the same one that would be chosen if the costs of building capacity were weighed against the benefits. For example, if consumers' valuation of capacity is not ascertained, how is the utility to know whether, at the margin, consumers would be willing to pay for a reduction in the probability of demand exceeding supply from 5% to 3% (*i.e.*, an incremental increase in reliability)?

The administrative rules used to ration water can also be criticised. Efficiency requires that the rationing rule minimizes the costs associated with demand exceeding capacity. These costs include the foregone benefits when customers' demands cannot be met, and the administration and enforcement costs of the rationing rule. An implication of including foregone benefits in the costs to be considered is that consumers should be rationed in descending order of their respective willingness to pay for water. That is, those who value it least should be the first to be restricted from consuming. However, this component of rationing costs is ignored completely by current practice. Thus, any rationing scheme which arbitrarily prohibits certain uses for water or reduces all customers' use of water by an equal proportion is unlikely to meet this criterion since the utility has no information regarding consumers' valuation of water.

Furthermore, there is no evidence that the current rules even minimize the administrative costs of rationing. In part, this is because the utility's strategy does not rely on price to ration output. Unlike most other instances when the increased scarcity of a commodity leads its price to increase (such as strawberries in December), this is not the case for municipally-supplied water. For example, in the case where all users are metered, it might be less expensive simply to announce short-run price increases during times of water shortages rather than rely on directives which request or even order the curtailment of water use.

EFFICIENT PRICING AND CAPACITY RULES UNDER UNCERTAINTY

This section provides an intuitive description of a theoretical model that derives efficient pricing and capacity rules for a public water utility facing demand uncertainty. An algebraic treatment of this theoretical model is available in Crew and Kleindorfer (1986), and Rees (1984).

The water utility is assumed to set its price and level of capacity to maximize the expected social net benefits associated with the consumption of its output. The net benefits to society are taken to be the difference between gross benefits and the cost of supply. The former is approximated by consumers' aggregate willingness to pay as expressed in the market demand for water. The latter includes all of the costs associated with water consumption including the value of raw water and the costs of water rationing.

When choosing its price and capacity, the utility faces two fundamental constraints. The first is the current technology of water supply which specifies the maximum level of output achievable from different quantities of inputs. The second constraint arises from the assumption that when the utility makes its decisions regarding price and capacity, it does not know the demand for its output. Specifically, it is assumed that the market demand has two components: a deterministic component (which the utility may forecast with certainty), and a stochastic component. The utility knows the probability distribution of the latter component but cannot predict *ex ante* what specific value it will take. For example, the deterministic component could correspond to the long-run trend in water consumption, and the stochastic component could come from the short-run fluctuations in water use due to changing weather, incomes or business activity.

For simplicity, the cost structure of the utility is assumed to be linear in the quantity of output and the level of capacity. Thus, there are constant marginal costs of operations and capacity expansion. It should be noted, however, that because output is stochastic, so will be total costs. In the event that demand exceeds the installed capacity, the utility will face a third type of cost associated with the scheme it uses to ration output amongst competing consumers. These rationing costs can be thought of as having two parts. The first is the added administrative cost of implementing and enforcing the rationing rule. The second is the cost to society of foregone net benefits due to the fact that some consumers cannot purchase their desired quantity of water.

RESULTS

The water utility chooses the price of water, the system capacity and the form of the rationing rule to maximize expected net social benefits. Once chosen, these variables exhibit some important characteristics which may be summarized here.

The price which maximizes the expected social net benefits from consumption in the uncertainty case is the stochastic analogue to the efficient price under certainty. Thus, if price and capacity are chosen simultaneously, price should be set to equal expected long-run marginal cost. The latter has three components: marginal operating costs, marginal capacity costs and expected marginal rationing costs. The first of these three components has an important feature; it includes the full social cost of all of the utility's inputs, including the value of raw water. The last component of long-run marginal cost (the expected value of rationing costs) is included since the level of output is stochastic. Thus, there is some probability that demand will exceed capacity and, as a result, the utility will have to ration its output.

Thus, the commonly cited public sector pricing rule of setting price equal to long-run marginal cost can be extended to the case of demand uncertainty by explicitly incorporating the probability distribution of alternative demand states, and also the additional costs associated with the need to ration output when demand exceeds capacity. One implication of this feature of the efficient price is that any event which leads to a higher expected future demand will lead to a higher price. This is because an increase in expected demand, for a given capacity, will increase the probability of the need for rationing, and thus will increase expected rationing costs.

The utility must also specify the level of capacity before demand is known. The best way to understand the rule for the efficient level of capacity is to recognize that once the capacity is installed, it provides the same service (*i.e.*, available capacity) to each of the utility's customers simultaneously. Thus, it has the features of what economists call a 'public good'.

The condition for the capacity level to be efficient is an extension of Samuelson's (1954) rule for the optimal provision of a public good to the case where demands for that public good are uncertain. Specifically, the chosen level of capacity must satisfy the following condition: the expected marginal willingness to pay for a small increase in capacity must equal the marginal cost of expanding capacity by that amount. The expectation is again taken over the probability distribution of alternative levels of demand.

In order to see the intuition behind this condition, suppose that at the current level of capacity, consumers' willingness to pay (appropriately weighted by the likelihood of alternative states of demand occurring) exceeds the marginal cost of expanding capacity. For example, suppose that there are 100 identical consumers, each of whom would be willing to pay $2 for an additional unit of capacity in hotter than average weather and $0.40 in average weather. Further, assume that there is a 50% chance that the weather will be hotter than average and that the increment to capacity will cost $100 to install. In this example, the expected aggregate willingness to pay for capacity expansion is $120 and the marginal cost is $100. Thus, the value to society of enjoying a slightly higher level of reliability exceeds the cost of doing so and the utility should install the capacity.

It is worth pointing out that choosing the level of capacity is equivalent to choosing a level of reliability. Thus, the optimal capacity implicitly defines an optimal level of reliability which balances the consumers' desire for greater capacity (and, thus, more reliable service) with the cost of that capacity. This differs from current practice where a system's capacity is designed to meet the reliability levels set by utility planners.

The last feature of the utility's operations under demand uncertainty is its rationing scheme. To be efficient, the rationing rule must recognize that foregone consumption represents a cost to society. Thus, the scheme should be structured so that users' valuation of water is elicited and that the highest value uses have the first claim on the scarce supply. It is worth pointing out, however, that the degree of complexity of the rule (and, therefore, its costliness) should also be governed by efficiency considerations. That is, the costs of making the rule more sophisticated (and more costly) must be weighed against the benefits in the form of ensuring that the water goes to higher valued uses. For example, a rationing scheme that would be efficient and relatively simple to adopt would have the utility allow people to buy different grades of water supply, where a lower price would be understood to imply an acceptance of specific restrictions on the allowable types of water use during periods of shortage.

One implication of the general rule for the design of rationing rules is that rationing rules which eschew information on users' valuations will usually be inefficient. Examples of these type of rules would include random rationing (where the water pressure over the entire system is reduced and, as a result, users are rationed randomly), and administrative rationing (where users are rationed according to some arbitrary characteristic such as their addresses).

The model of utility operations can be extended in several directions in order to incorporate other features of the environment facing water utilities. First, in contrast to the assumption made in this paper, it can be assumed that the utility must choose its capacity without knowing the level of demand but that it may wait to set price until the level of demand is known. In this setting, the utility can raise or lower price to ensure that quantity demanded does not exceed capacity. This use of price to ration output would ensure an efficient allocation of the scarce capacity.

Second, allowance can be made for cyclically fluctuating demands. In this case, the actual level of demand is unknown *ex ante*, but the utility does know that, on average, demands are higher in summer months than in the remainder of the year. Then, if the entire year can be divided into 'peak' and 'off-peak' periods, stochastic analogues to peak-load prices can be derived. That is, prices in each period will still depend on operating and expected rationing costs, but prices in the peak period will exceed those in the off-peak period because they also include marginal capacity costs.

Third, the model can incorporate a zero-profit or break-even constraint. In this case, expected revenues must be at least as great as expected costs. This new constraint may be met either by introducing a second type of price (*e.g.*, an annual charge for connection) or by allowing the price of water to rise above expected marginal cost by the smallest amount necessary to recover the deficit.

CONCLUSIONS

What are the policy implications of the arguments made in this paper? First, water utility planners must re-orient their thinking so that decision making reflects the scarcity and value of the resources (natural and human) being employed. Second, prices at every point in time and at every location should inform the consumer of the full social costs of their consumption decision. Finally, the presence of demand uncertainty complicates the rules to be followed for efficient prices and capacity but does not alter them fundamentally. For example, when choosing its capacity, a utility must compare costs and benefits but, in the case of uncertain demands, these benefits must be weighted by the probability of alternative states of demand occurring.

The principal obstacle standing in the way of reforming water prices stems from the startling lack of information regarding the characteristics of water consumption in Canada. Before any serious attempt is made at changing water prices on a large scale, research is needed to understand better the features of water demands and the factors affecting the cost of water supply. Based on the arguments presented here, the following areas should receive priority for future study: the valuation of water and the variability of water use for different user groups, the value of raw water supplies and the relative costs and benefits of alternative water rationing schemes.

ACKNOWLEDGEMENTS

I would like to thank Diane Dupont for her valuable comments and Phil Nehr and Ray Rees for their comments on an earlier, related project. Financial support from SSHRC is gratefully acknowledged. All errors and omissions remain my responsibility.

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CHAPTER 20

PREDICTING PEAK WATER DEMANDS FOR A MUNICIPAL WATER SUPPLY SYSTEM

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Christine A. Jany

INTRODUCTION

In the mid-1980s, the London Public Utilities Commission (PUC) recognized that the Lake Huron Water Supply System, which is London's main water supply source, was approaching its design capacity. The dry and hot summers of 1987, 1988 and 1989 stressed the supply system to its capacity, and added greater urgency to London's need to acquire additional water supplies or to curb the City's growing appetite for water. Studies conducted by M.M. Dillon Ltd. in 1990 clearly indicated that, if growth in water demand continued as it had over the last two decades, then the City risked severe water restrictions in the event of another dry summer.

Coupled with the apparent deficit in supply capacity, was the continuing concern with the structural integrity of the Lake Huron Water Supply System 50 km transmission main from Grand Bend to Arva. Two significant ruptures in the main occurred in 1983 and 1988, leaving the City to rely on water stored in reservoirs at Arva and Springbank Park, plus water from stand-by well fields which the PUC maintains for this purpose.

To alleviate the supply deficit and the security concern, the London PUC requested the Ministry of the Environment (MOE), which owns and operates the supply system, to provide the City with additional supply capacity. In addition to proceeding with new supply capacity studies, the London PUC embarked on a more aggressive water conservation program. The London PUC has always advocated the principles of full metering for all their accounts and the user pay principle to ensure responsible water supply management - the cornerstones of conservation initiatives.

The focus of the more aggressive conservation program was to implement an increasing block rate structure for residential customers (one of the few in Ontario), and to support the initiative with a widely-based advertising and education program. The focus of the conservation program was twofold. First, it was to reduce total annual consumption (measured as average day demand) by encouraging the use of water conserving fixtures, such as low flow showerheads and low flush toilets. Second, it was to reduce maximum day and peak hour demand by discouraging wasteful practices in outside water uses such as lawn watering and car washing. In the recent drought years in the southwestern United States, we have witnessed the significant draw-down of major supply source reservoirs, resulting in a communities' need to reduce total annual water demand (Shaw and Maidment, 1988; Cuthbert, 1989; Rhoades and Walski, 1991).

In the Great Lakes watershed, our supply sources are not constrained and we are, therefore, not as concerned with reducing total annual demand (measured as average day demand). We are more concerned with reducing our maximum day demand because this is the factor which stresses Great Lakes water supply systems. It is clear that a permanent reduction in the maximum day per capita demand rate would defer future capital expenditures for water treatment plants, pump stations and reservoirs, even with continued urban growth. While all of these initiatives are laudable, we as planners and engineers must have the necessary tools available to us to measure whether our conservation initiatives are effective.

Since maximum day demands are generally related to outside water uses, and these uses in turn are related to meterological conditions, it is not readily apparent whether changes in demand from one year to the next are related to changes in discretionary usage patterns or in weather patterns. This paper develops a model which will assist in making this assessment.

Additional impetus for the model arises from the need for an operational tool to increase the confidence with which water supply operators can predict short-term (3 to 5-day) water demands. Current operating practices at London PUC reservoirs, in an effort to reduce power costs and shift electrical load to off-peak periods (11:00 p.m. to 7:00 a.m.), has led to optimization of reservoir storage levels. Traditionally, reservoirs have been maintained at high levels to ensure maximum water volumes in the event that demand increases dramatically or an emergency occurs. By allowing these reservoirs to be drawn down during the day and replenished overnight, significant power savings can be realized if the utility is subject to a 'time-of-use' electrical tariff structure. By being able to more accurately predict water demand, even three days in advance, additional savings can result with less risk to the customer.

Over the next few years, until additional supply capacity is provided, London's water supply system will undoubtedly be stressed again during another hot dry spell. The London PUC will have to invoke total lawn watering and outside water use bans. Significant depletion of the City's reservoirs can result from the time that the ban is put into effect until the time that customers respond to a significant degree (from 24 to 48 hours). In the past, City industries have been requested to cut back on their consumption in these high demand periods.

By having a predictive water demand model, the water bans could be announced earlier, avoiding the 'crying wolf' syndrome, and industrial cutbacks. Such a tool would undoubtedly increase consumer confidence in the utility's ability to run a water supply system in times of constraint.

DEVELOPMENT OF THE MODEL

A model was developed in order to explain the daily variation in consumer water demand during the peak consumption months of June, July and August. The variation appears to be the result of outdoor water use (*e.g.*, lawn watering) and an established weekly demand pattern, mainly influenced by industrial consumers. Meteorological data was used in the model to explain the outdoor water use variation.

By performing a multiple factor regression analysis on historical data from 1981 to 1990, the following equation was developed:

$$\frac{\text{DAILY WATER DEMAND (ML/D)}}{\text{YEARLY WINTER AVERAGE DAY DEMAND (ML/D)}} = 7.3963\ \text{(WEEKLY FACTOR)} + 0.0176\ \text{(MAXIMUM DAILY TEMPERATURE °C)} + 0.0122\ \text{(DAYS WITHOUT RAIN)} + 0.0049\ \text{(SOIL MOISTURE DEFICIT mm)}$$

For each year of record, the daily water demand was divided by the winter average day to factor out increases in water demand due to growth in population and per capita usage. The daily water demand data were obtained from the London PUC. The weekly factors represent the percentage of total demand which occurred on each day of the week over the period 1981 to 1990.

The maximum daily temperature, number of days without rain and soil moisture deficit data were determined using meteorological data. All meteorological data, with the exception of evaporation records used to calculate soil moisture deficit, were taken from Environment Canada Atmospheric Environment Service (AES) Monthly Meteorological summaries for the London "A" Station. Evaporation data were obtained from the nearest AES station recording this data, Delhi CDA. The soil moisture deficit represents the amount of water stored in the soil and was calculated on a day-by-day basis using precipitation and evaporation data (Bruce and Clark, 1975).

In an attempt to explain human perception and response to meteorological data, the following assumptions were made. It was assumed that above a threshold limit of 2 mm of precipitation per day, the perceived need to water outside would diminish. Thus, the soil moisture deficit was reset to zero. It was also assumed that if the soil moisture deficit reached 40 mm, then the need to water outside would level off. At a soil moisture deficit of 40 mm, grass begins to wilt and turn brown (Bruce and Clark, 1975). The final assumption concerned the number of days without rain. It was assumed that after 14 days without rain, the majority of home-owners are already watering their lawns and consumption does not increase any further.

COMPARISON OF PREDICTED DEMAND TO ACTUAL DEMAND

Figure 20.1 displays the results for the June, July and August 1991 values for the factors discussed in the previous section. This period can be characterized as relatively warm with only two dry spells exceeding seven days and these occurred in early June, after a wet spring, and in late August, at the point where most people have reduced their lawn watering practices.

Figure 20.2 compares the predicted demand as calculated by the model with the actual daily demand over the 3-month period. There are four significant over-estimations by the model, and one significant under-estimation. The over-estimations which occurred in early June and late August are easily explainable, as discussed above. For August, the model can be improved by using August historical data from 1981 to 1990. The error in the estimation is then reduced to approximately 5 percent, versus 10 to 15 percent when the predictive model uses all three months of historical data. These findings validate the observation that most residential customers alter their lawn watering practices in mid to late August.

Both the under-estimate of demand in late June and the over-estimation of demand in mid-July are unexplained by the meteorological data and may relate to industrial plant shut-downs in mid-July and a good soaking of the once lush lawns, turned brown, before the July long weekend.

The average error of the 1991 predictive model was compared to the other years of record (1981 to 1990) and found to be similar. We could infer from this finding that the increasing block water rate structure did not significantly affect lawn watering practices. That is to say, for the meteorological conditions experienced in London in the Summer of 1991, the normal amount of lawn watering was practised.

Many of those individuals, who proudly boasted about their brown lawns, discovered in the late fall that the culprit was the white grub and not the arid conditions many inferred. We may in fact see excess water consumption in 1992 as home-owners attempt to re-establish their lawns and drown the nasty pests.

Is the water conservation initiative of the London PUC effective? We cannot answer the question at this time, since the natural variation and

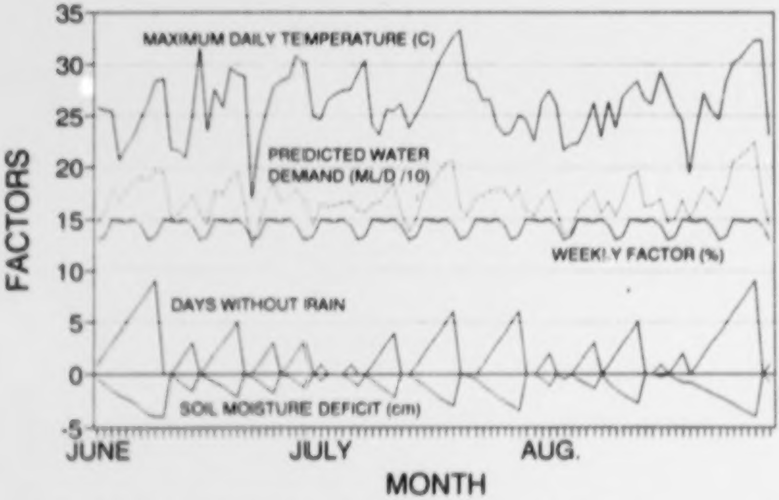

FIGURE 20.1. Predicted water demand and influencing factors for 1991

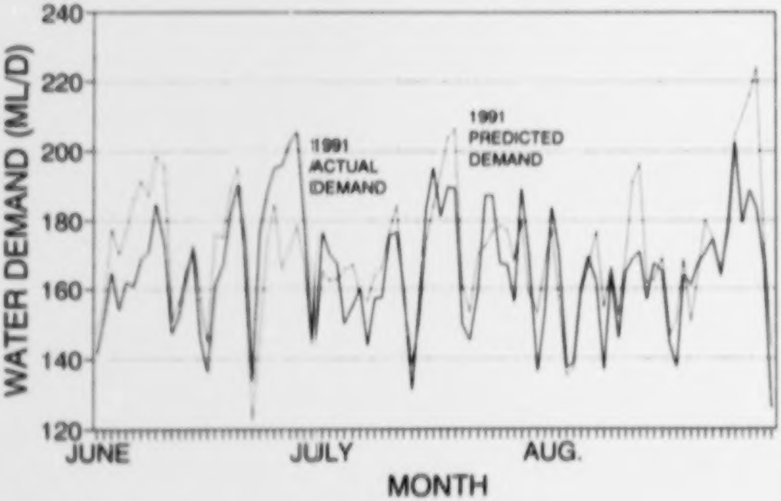

FIGURE 20.2. Actual versus predicted water demand for 1991

fluctuation in the daily data may be obscuring the change in usage patterns. Additional years of data will provide a clearer picture. Also, basing the assessment on total annual water consumption for residential users may be a more appropriate measurement tool to evaluate the total conservation effect (Cuthbert, 1989). Total water consumption techniques are not appropriate for measuring conservation effects on the peak usage periods which we were interested in.

CONCLUSIONS

The predictive model, developed using multiple regression analysis, is an effective tool for providing reasonably accurate demand forecasts three to five days in advance. The model can be used as an operational tool to optimize reservoir storage criteria to maximize 'time-of-use' power savings and to provide an early warning to order lawn watering bans.

Comparison of the model results using 1991 meteorological data and actual 1991 water demand, did not reveal a significant difference in the data sets. This would suggest that the water use pattern in 1991 was not significantly different from previous years. Because of the errors of the estimates inherent in the natural variation and fluctuation in water demand, the impact of conservation may be obscured. The model requires refinement to more accurately measure human consumptive behaviour and to account for anomalies in the data sets.

FUTURE REFINEMENT OF THE MODEL

The model developed for this paper was a first attempt to achieve a simple predictive tool using readily available data with minimal manipulation. We believe that the model could be significantly improved by including additional factors or adjusting the raw data to account for known events which have been currently ignored.

A more accurate demand model could be developed if the industrial and institutional water demands could be characterized on a daily basis throughout the summer. The model currently assumes that industrial and institutional demand is constant, except for the day of the week correction which has already been applied. A more accurate inventory of seasonal plant start-ups, temporary shut-downs and permanent shut-downs would improve the data set.

The historical demand data set could be improved by accounting for major distribution system or reservoir leaks, system flushing, fires and pipeline breaks.

More localized meteorological data would improve the accuracy of the model. A heavy rain at the London Airport could potentially miss the rest of the City. Pan evaporation data for Delhi may not be representative of London conditions.

The impact of previous watering control orders and total bans was ignored in the data set. These control orders obviously change normal watering practices and can significantly affect water demand patterns.

Establishing lawns in new housing developments can significantly increase water demand in years of rapid urban growth. This factor could be included in the model to improve accuracy.

General economic factors could also be incorporated to improve accuracy, although this may be more appropriate for a monthly model.

The model could also be improved by accounting for spring soil moisture conditions and the recognition of a lawn watering initiation threshold.

ACKNOWLEDGEMENTS

The assistance of the London Public Utilities Commission and the Ministry of the Environment is gratefully acknowledged, in particular John Braam, Elmon Nicolle and Ian Cameron, London PUC, and Andy Valickis and Bruce Boland, MOE.

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CHAPTER 21

WATER CONSERVATION IN THE PUBLIC SECTOR

D.M. Tate and D.A.G. MacMillan

INTRODUCTION

The past 10 years in Canada have marked a renewed interest in water conservation in Canada. Despite efforts in the earlier decades of the 20th century by the Conservation Commission, the supply-oriented approach to water management remained prevalent well into the 1980s. Changing social, economic and environmental conditions have forced managers to look increasingly at water conservation as an alternative method of resource management. The lack of inexpensive supply alternatives, the increased cost of water developments themselves, the increasing cost of capital itself, and a new-found public agenda to protect and preserve the environment, all contribute to the renewed interest in water conservation.

Water conservation here is taken to be any socially beneficial reduction in water use or water loss. The 'social benefit' context means that proposed water savings should also make sense economically, a particularly important condition in a relatively water abundant country like Canada.

Recently, several studies have concentrated on examining water use in public buildings. The federal government's *Federal Water Policy* and the subsequent *Green Plan* initiated an interest in improving the water use efficiency in all sectors of the Canadian economy. The federal government itself reasoned that this interest in water use efficiency implied a sustained effort to improve efficiency at it own installations. Concurrently, provincial governments, notably Ontario and Alberta, have developed similar programs.

This paper examines the issue of water conservation efforts by the public sector. Two principal objectives are important here. The first is to indicate some of the broad economic 'payoffs' resulting from water conservation in the public sector, including those to the municipal infrastructure. This discussion forms a context to examine a few of the studies recently carried out to examine water use in public buildings. The results of these studies are also presented.

ECONOMIC ASPECTS OF WATER CONSERVATION

Canada controls approximately 9% of the world's annual renewable water supply (Pearse *et al.*, 1985). Distribution and quality of the resource vary substantially across the country, and various areas can experience water shortages from time to time. Also, much of the water flows northward, away from population centres. These qualifications notwithstanding, much of Canada has sufficient water to meet current and future needs.

In spite of these basic geographical factors, Canada can reap substantial economic benefits from concerted water conservation efforts. The municipal infrastructure issue provides some insight into these benefits.

There is little doubt that municipal water infrastructure has deteriorated in quality over the past decade. In 1985, the Federation of Canadian Municipalities (FCM) documented some aspects of this decline. Its study found that decreasing proportions of local public works budgets were being devoted to basic services such as water and waste treatment, and more to 'visible' assets, such as arts centres, recreational complexes and the like. This study also documented the declining financial contributions to infrastructure by senior levels of government. Finally, the study showed that the shortfall in funding required to upgrade systems to meet then-current standards was about $12 billion over a five-year period. Approximately 50% of this amount related to water infrastructure (*i.e.*, water supply and distribution, waste collection and treatment). The $6 billion amount is likely in the range of $8 - $10 billion today, allowing for inflation and further deterioration. These figures should be treated with some caution, since no comprehensive, independent and authoritative study on this issue has been done to confirm the FCM estimates. But, for the purposes of this paper, we have taken the $10 billion estimate to approximate the funding shortfall.

Approaching this issue from a somewhat different perspective, it is possible to examine how municipalities raise funds for water services, and why funding shortfalls have occurred in the past. While there have been (and still are) grants from senior governments (primarily provincial), the majority of funding for municipal infrastructure has been derived from water rates charged to users. The latest federal government survey of water rates, for 1989, showed that two types of rate structure, flat rates and declining block rates, dominate current practice (Tate and Lacelle, 1991), as they did in 1986. Together, these two rate structures account for about 70% of those in current use. Both rate structures provide significant disincentives for water conservation, by charging marginal prices which are effectively zero, or which decline as user water demands grow.

Not only are Canadian water rates poorly structured, they also result in water prices to consumers that are very low, both in terms of absolute values and relative to the prices of other goods and services. For instance, the average price of water servicing (*i.e.*, supply and waste treatment) per residential connection across Canada is under $20 per month. This amount translates to an average price for water of between $.50 and $.60 per cubic meter.

Using the 1989 municipal water pricing data, it is possible to estimate total municipal water revenue. When applied to Ontario, this approach produced a revenue of $1.1 billion per year. Using independent and provincially-collected data on annual costs and revenue, the revenue for water utilities totalled $1.2 billion for 1989. Thus, it seems reasonably accurate to produce estimates of total revenue from the water rate data. When we did this estimate, total national revenues from water rates totalled about $3 billion for 1989.

One major instrument for bringing about increased water conservation involves raising water prices to levels where users pay the full costs of water servicing. In general, higher water prices will lower demands, lower capital requirements over the long term, and raise more revenue for the respective water utilities. The revenue raising capability for the industry is quite large, since the demand elasticities for municipal water are substantially below 1. At the national level, a doubling of water prices would imply increased expenditures of $20 per month per residential connection - less than a monthly cable T.V. bill. The total revenue generation estimate would total between $2 billion and $2.5 billion, allowing for a drop in demand following the price increase. This amount would cover the cost of infrastructure upgrading within a reasonably short 4 to 5-year period.

The argument presented here, of course, is somewhat abstract because local conditions vary, both economically and with regard to revenue requirements. Also, the issues of how to structure water rates and of universal metering have not been addressed here. But, we believe that the general finding is correct - namely, that sufficient local funding could be found to pay most or all of the cost of infrastructure upgrading. More generally, the message is that conservation-related actions, such as higher water prices, can result in lower operation and maintenance costs and long-run capital savings, and substantial revenue generation. The following section develops the point about savings in more detail in the context of water conservation at public facilities.

WATER CONSERVATION AT PUBLIC FACILITIES

Water usage and rates paid by public institutions for water is not well researched anywhere in North America. The federal *Green Plan*, promulgated in 1991, contained a section on environmental stewardship. It stated specifically that the federal government should run its own facilities in an environmentally sound manner, and one of the areas slated for action was water conservation. This declaration prompted the collection of water usage data in federal facilities.

Although the data collected were incomplete, the results of the data analysis indicated that the federal government used in excess of 12 million m^3 in 1990 in the National Capital Region alone. Spending on water and sewage services totalled at least $12.5 million. The data we examined over time, and it was found that, although water usage had dropped between 1989 and 1990, the amount paid rose substantially, because of a rise in regional water rates. The rise in water rates seems likely to continue over the next few years, making water conservation an obvious candidate to save money. Accordingly, a series of pilot water audits were begun, and, at the time of preparing this paper, are still being finalized. Thus, it is not possible to report here on the magnitude of savings possible through water conservation in the NCR area. However, the auditing process was based on the results of two previous studies which had been done at the Canada Centre for Inland Waters (CCIW) in Burlington and Warkworth Correctional Centre in Eastern Ontario. The following sections briefly describe these studies.

The CCIW Water Audit

The CCIW research/laboratory facility, opened in 1967, occupies 47,700 m^2 of mixed use floor area in seven wings of a single structure. It occupies a site on the shore of Hamilton Harbour, at the west end of Lake Ontario, one of Canada's most water abundant areas. In the past, water conservation and cost saving actions have occurred, partially in response to the environmental commitment of building employees. For example, since 1985, uncontaminated water has been diverted through a storm sewer into Hamilton Harbour. The resulting decreased flows to the municipal waste treatment plant led to a credit on the facility's water bill from the local water authority. Other water conserving efforts have included:

- replacement of automatic flush to manual units in urinals;
- installation of water meters to monitor water use and allocate costs;
- use of harbour water for lawn irrigation; and
- reduction of flush/refill frequency in tanks and flumes by decreasing the algae growth rate.

The result of these actions is a water and sewerage bill of about $160,000 in 1991, net of city rebates.

The CCIW facility was a good location for a pilot water audit, since water availability presents no problem currently, or in the foreseeable future. If conservation savings are possible here, they would likely be feasible and even more attractive in other locations. Accordingly, a private consultant was retained to carry out a water efficiency audit, at a cost of $26,000 (Proctor and Redfern Ltd., 1991)

A three-week period of flow monitoring indicated that the average estimated water demand (including some recycling) at CCIW totalled 717 m^3 per day. Over the recording period, base flow comprised 70% of continuous flow. Two areas contributed most to the total water use:

- fisheries laboratory (183 m^3 per day of which 174 m^3 is discharged); and
- administration and laboratory wing (299 m^3 per day, of which 200 m^3 per day is used for once through cooling and subsequently discharged).

Water usage was classified into four categories (Table 21.1), represented by a percentage of municipal water intake accounted for through metering (665 m^3): cooling (50%), process (36%) domestic (7%) and laboratory (7%).[1] Estimated domestic use averaged 65 litres per capita-day.

The main recommendation of the study concerned curtailing cooling water demands. Due to the proximity of CCIW to a large water body, all cooling water can be drawn directly from the harbour. The cost of intake development to replace municipal water (327 m^3 per day) was estimated at $101,000. The implementation of this alternative would result in an annual cost saving of $53,000, with a resultant payback period of under two years.

At 34%, the fisheries laboratories' tanks used the second-largest volume of city water. The cost of recycling a portion of the once-through cooling water for process applications totalled $23,350. With an annual saving of $22,600, the resultant payback period would be just over one year.

Other measures examined, but for which no costs were calculated, included moving certain laboratory operations to lower water use periods, reactivating the existing pressure-reduced cold water network to achieve water use reductions, and better use of existing/new water meters to monitor use. Since retrofitting of lavatory facilities had been completed already, further cost savings in this area, normally significant item in most buildings, were not anticipated.

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[1] An additional 52 m^3 of municipal water, measured at the main facility intake, could not be accounted for by internal metering.

TABLE 21.1
Canada Centre for Inland Waters
Category of Water Use Summary

Category	Location	City Water Inflow (m^3)	Discharge	
			Storm (m^3)	Sanitary (m^3)
Cooling	Boiler Plant	40		40
	Hydraulics Lab	6		6
	Research & Development	28		28
	Administration & Lab	251	200	51
	WTC	2		2
	Total (50%)*	327	200	127
Process	Boiler Plant	20	8	
	Hydraulics Lab	26	26	
	Fisheries Lab	177	133	44
	WTC	26		26
	Total (36%)*	249	167	70
Domestic	Boiler Plant	10		10
	Hydraulics Lab	2		2
	Research & Development	4		4
	Administration & Lab	23		23
	WTC	6		6
	Total (7%)*	45		45
Laboratory	Boiler Plant	3		3
	Fisheries Lab	6		6
	Research & Development	3		3
	Administration & Lab	25		25
	WTC	7		7
	Total (7%)*	44		44

*Percent of total City Water Inflow, including unaccounted-for water.

Warkworth Correctional Institution

Warkworth Institution is located near the community of Bath in southeastern Ontario. It draws its water supply from the Trent River, some 2 km from the facility. The Centre consists of some 44 buildings, and houses an inmate population of 500 persons, with a total staff of 400. In the course of upgrading and expanding the prison facilities, the water supply and sewage treatment facilities came under scrutiny. Among the observations made were:

- an apparent water demand approximately 50% of the water actually recorded as entering the treatment plant (Figure 21.1);
- a high per capita water demand (668 litres per day), which seemed unreasonably high, compared to values quoted in the literature, and those at similar sites in other parts of Canada.
- inadequate and dysfunctional water metering, which did not permit even a cursory accounting for water use among the various buildings.

The water use audit took place over a four-week period in 1991 (CH2M Hill Ltd, 1991), and found that the estimated average water demand at the facility was 259 m^3 per day throughout the year, rising to an average of 519 m^3 during the summer. With the planned expansion of the facility, water demand will rise an estimated 9%.

Through its detailed metering program, the audit found a substantial difference (about 50% of summer demand) between the water supply rate and the estimated demand rate for this type of facility. A major leak was located and repairs undertaken, resulting in cost savings of around $19,000 per year, with a very rapid payback period. The audit also identified a number of cost-effective methods of reducing water use, while maintaining the quality of service. These included:

- installing low flow shower heads;
- replacing water cooled air conditions with air cooled units;

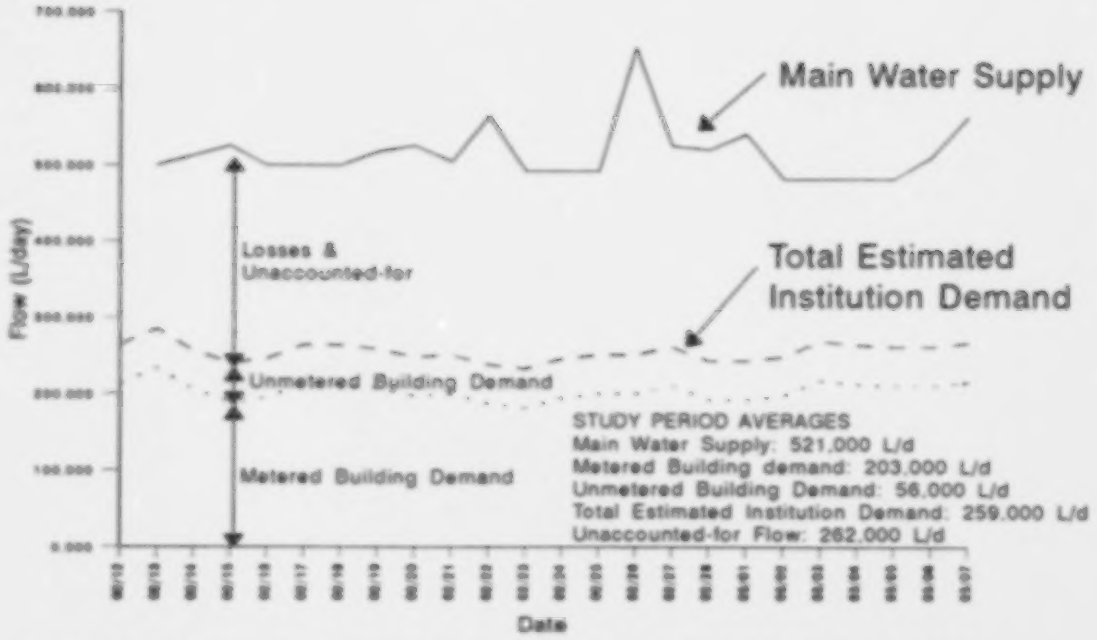

FIGURE 21.1. Comparison of water supplied with demand over the monitoring period at Warkworth Institution

- turning down water cooled compressors to minimum flow, and turning them off during the summer;
- installing flow aerators in mess sinks; and
- installing pressure spray gun on outside lawn and garden irrigation equipment.

Total annual cost of these revisions cost estimated at $36,500. With an annual saving of about $16,000 in operation and maintenance costs, the payback period for the entire upgrade is about 2 years.

More importantly, the water audit led directly to eliminating the need for a $150,000 capital investment for an new water filtration plant. In addition it delayed, by several years, the requirement for a $350,000 expenditure at the existing sewage treatment plant. Overall, Correctional Services Canada officials estimate that the total cost savings resulting from this audit, calculated in present value terms, is about $5 per cubic metre of water saved.

Water Audits in Ontario

In 1991, the Province of Ontario conducted water audits at five government-owned buildings. The buildings represent a good cross-section of typical government-owned facilities. The study was done to determine the magnitude of possible cost savings through water conservation at public facilities. The results confirm that there are major economic benefits (Table 21.2) for the owners of public facilities from investing in a water conservation program. The Ontario audits were of an overview nature, and did not involve the degree of metering and other detailed work that was done for CCIW and the Warkworth facility. Nevertheless, the results point out the same degree of both water and economic savings.

CONCLUSIONS

This paper has presented an overview of the economic savings to be realized through water conservation. The first section provided an overview of the municipal water infrastructure financing problem. We believe that

TABLE 21.2
Potential Water Conservation Savings at Selected Ontario Government Facilities

Facility	Annual Water Savings ('000 m^3 and [% current use])		Retrofit Costs ($000)	Annual Cost Savings ($000)		Payback Period (years)
				Water	Water + Energy	
719 unit highrise apartment bldg.	73	[60%]	171	58	79	2 - 3
Major office complex	60	[85%]	144	48	48	2 - 3
Small thermal power plant and lab	58	[93%]	64	43	46	1.5
Courthouse	2	[70]	3	1	2	2
Medium sized office building	18	[78]	16	14	14	1

Source: Ontario, Ministry of Natural Resources, 1991.

water conservation holds one of the keys to financing future infrastructure needs. While there may need to be limited funding from other levels of government, the concept of realistic water pricing, accompanied by universal metering, is capable of generating most of the required funds. The second part of the paper expanded upon this theme of economic savings through conservation. Water use audits have shown the potential savings possible at public building, within very reasonable payback periods.

ACKNOWLEDGEMENTS

We appreciate the input provided by B. Muise, Correctional Services Canada, T. Hamory and P. Dossett in the preparation of this paper.

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CHAPTER 22

LAKE LEVEL IMPACTS ON RECREATION VALUES: THE CASE OF LAKE DIEFENBAKER AND THE 1984 DROUGHT

R.D. Bjonback

INTRODUCTION

The summer of 1984 witnessed the longest sustained period of extremely low water levels at Lake Diefenbaker, located on the South Saskatchewan River in Saskatchewan, since its creation in the late 1960s. A wide variety of uses were impacted by water levels that remained three or four metres below normal. A cross-lake ferry had operational difficulties, and various problems were encountered with recreation facilities, including inoperable boat launching facilities, navigation hazards for pleasure boats, and reduced appeal of beaches due to blowing sand and exposed silt (Beak Associates Consulting Ltd., 1987).

This paper examines the impacts of this event, and determines the economic implications for a key recreation site on Lake Diefenbaker, Danielson Provincial Park. Data was acquired through a survey of park users conducted during the peak of the recreation season, from Canada Day (July 1) to Labour Day (September 3), 1984. Respondents were interviewed to identify the implications of low water levels on lake use, and to assess willingness-to-pay to experience an improvement in water levels.

Recreation outdoors, such as that at Lake Diefenbaker, is a service that is not normally traded in markets. Economists have developed methods to simulate markets in order to assess the value of recreation sites and changes in their quality. In order to capture the economic implications of the reduced quality of the recreation experience, the survey provides the basis to apply a composite Travel Cost-Contingent Value model to this issue. The results of these models are assessed, by comparison to other similar studies, and the usefulness of these models for policy purposes concludes the paper.

LAKE DIEFENBAKER: CHARACTERISTICS AND USES

The South Saskatchewan River watershed rises as the Bow, Oldman, and Red Deer Rivers on the eastern slopes of the Rocky Mountains of Alberta, flows across the prairies through Alberta, joins the North Saskatchewan River in Saskatchewan, and enters Manitoba to eventually empty into Lake Winnipeg and Hudson Bay. The Saskatchewan-Nelson is the fourth longest river system in North America, and supports about 70 percent of Canada's irrigation developments (Bowden and Anderson, 1985), as well as thermal power, recreation, and municipal and industrial uses, as it flows through the semi-arid prairie landscape.

Irrigation and associated dams, reservoirs and diversion works, provided the engine to initiate regional development at the turn of the century in Alberta. The harnessing of the more reliable, higher quality mountain runoff, in comparison to the sparse, erratic, and poor quality waters originating on the prairie, made possible the growth of intensive agriculture, associated industries, and population.

Prior to the construction in the 1960s of the Canada-Saskatchewan South Saskatchewan River Project, which created Lake Diefenbaker, the South Saskatchewan River in Saskatchewan was very lightly used (Canada-Saskatchewan South Saskatchewan River Basin Study, 1991a). Lake Diefenbaker, which was formed by the construction of the Gardiner and Qu'Appelle Dams, is the centrepiece of the multi-purpose water management and economic development project.

Lake Diefenbaker provides an assured, high quality source of water supply to a broad region of south-central Saskatchewan, supporting industrial (potash mines) and irrigation developments, and municipal water utilities, including Regina-Moose Jaw. The lake also functions as a reservoir for water-based recreation, hydroelectric power generation, flood control and to regulate flows for areas downstream of Gardiner Dam on the South Saskatchewan River (for example, Saskatoon).

Almost all of the flows entering the lake from Alberta originate in the Rocky Mountains, so that operation of the lake depends upon effective forecasts of mountain snowpack, as well as reservoir carryover from the previous year. Runoff peaks typically in early July, and the intent is to have Lake Diefenbaker full by the autumn (Canada-Saskatchewan South Saskatchewan River Basin Study, 1991a). This provides maximum head for hydro-power generation during winter peak demands, and meets the need of uses which withdraw water from the lake, and water-based recreation.

Full supply level for Lake Diefenbaker is 556.87 m. The preferred elevation for most recreation uses is 554.0 to 555.5 m. A recreation water level target of 555.0 m to 555.3 m for July 1 has been established by the South Saskatchewan Reservoir Board and appears to be very satisfactory for recreational users (Beak Associates Consulting Ltd., 1987).

In dry years, releases from Lake Diefenbaker are reduced as much as possible, while still maintaining minimum flow requirements downstream. This still may be inadequate for maintaining water levels sufficiently high around Lake Diefenbaker, primarily pumping facilities for irrigation uses, and water-based recreation.

The majority of recreation uses prefer minimum lake levels in the range between 552 m and 554 m. Below 552 m, most recreation uses face severe constraints (Beak Associates Consulting Ltd., 1987). Impacts include lack of sufficient draft for boat launches and piers at some locations, swimming areas become muddy, and expanded beach areas become subject to dust storms. However, not all recreation uses are adversely affected to the same degree, as some boat launches are designed to operate at extreme low levels, and some uses, such as sport fishing, prefer lower levels as fish populations are more concentrated, leading to greater angling success.

WATER-BASED RECREATION DEVELOPMENTS: OPPORTUNITIES AND CONSTRAINTS

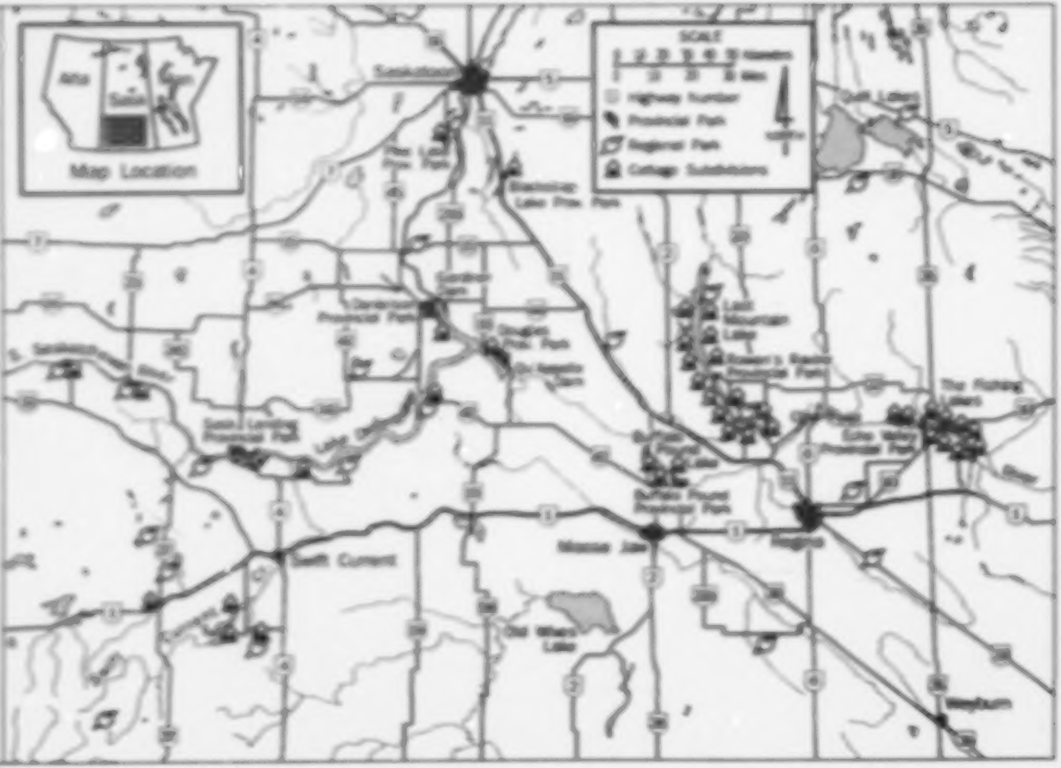
Lake Diefenbaker is the largest and highest quality water body available for water-based recreation in south central and western Saskatchewan. There are three Provincial Parks, four Regional Parks, four institutional camps, and four cottage subdivisions adjacent to the reservoir (Figure 22.1). The facilities support the widest range of water-based recreation activities, including unique activities to the western Prairies, such as fixed-keel sailing.

Alternative (and closer) recreation sites for the residents of the region, particularly for residents of Regina-Moose Jaw and Saskatoon, suffer from overcrowding, and relatively poor water quality conditions, including algae and weed growth (Richards, 1977). Lake Diefenbaker has considerable potential for further development (Hilderman *et al.*, 1984). An unspoiled semi-arid valley landscape, blended with excellent water quality, in terms of clarity and lack of weed growth, make the lake extremely attractive. High winds (which are an attraction to some uses such as sailing), a lack of tree cover, and lack of road access to much of the lake, however, are significant constraints.

Low water levels during the summer recreation season (Provincial Parks are open between Victoria Day and Labour Day) are reported to be a significant constraint to recreation use of Lake Diefenbaker. In 1984, media coverage of the low water levels discouraged recreational users from visiting the park (Beak Associates Consulting Ltd., 1987).

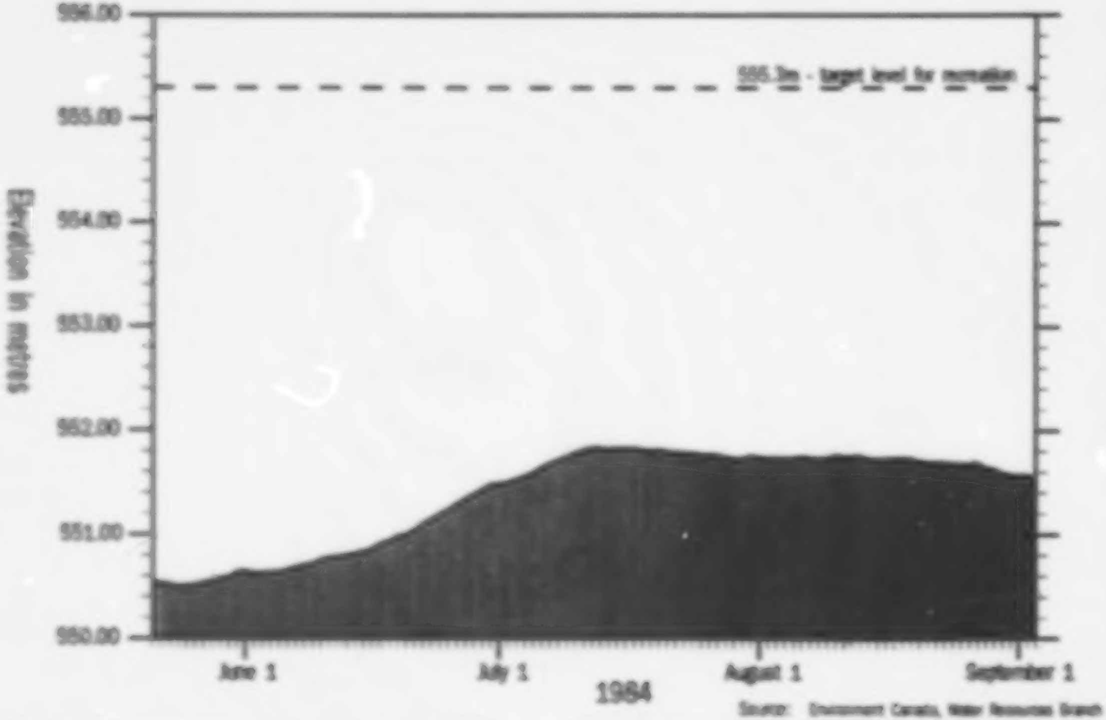
Indeed, 1984 was particularly unique in both extreme lows (two to four metres below desirable range) and extreme duration, for the whole summer period (Figure 22.2). For the period of record, 1969 through 1991, only 1977 and 1988 rival these extreme lows and duration of lows. However, in 1977 and 1988, lake levels did recover somewhat by mid August to just surpass 552 m, the lower bound of the minimum range for recreation use. Levels in 1984 never achieved this minimum.

The longer-term visitation data for the three provincial parks at Lake Diefenbaker are not definitive in identifying a close relationship between summer lake level and visitation (Figure 22.3). Vehicle entries


Map Location
Alta
Sask
SCALE
Kilometres
Miles
Highway Number
Provincial Park
Regional Park
Cottage Subdivisions
Saskatoon
Pike Lake Prov. Park
Blackstrap Lake Prov. Park
Quill Lakes
Danielson Provincial Park
Gardiner Dam
Douglas Prov. Park
Lake Diefenbaker
Saskatchewan Landing Provincial Park
Last Mountain Lake
Rowan's Ravine Provincial Park
Buffalo Pound Lake
Buffalo Pound Provincial Park
Echo Valley Provincial Park
The Fishing Lakes
Regina
Moose Jaw
Swift Current
Old Wives Lake
Weyburn

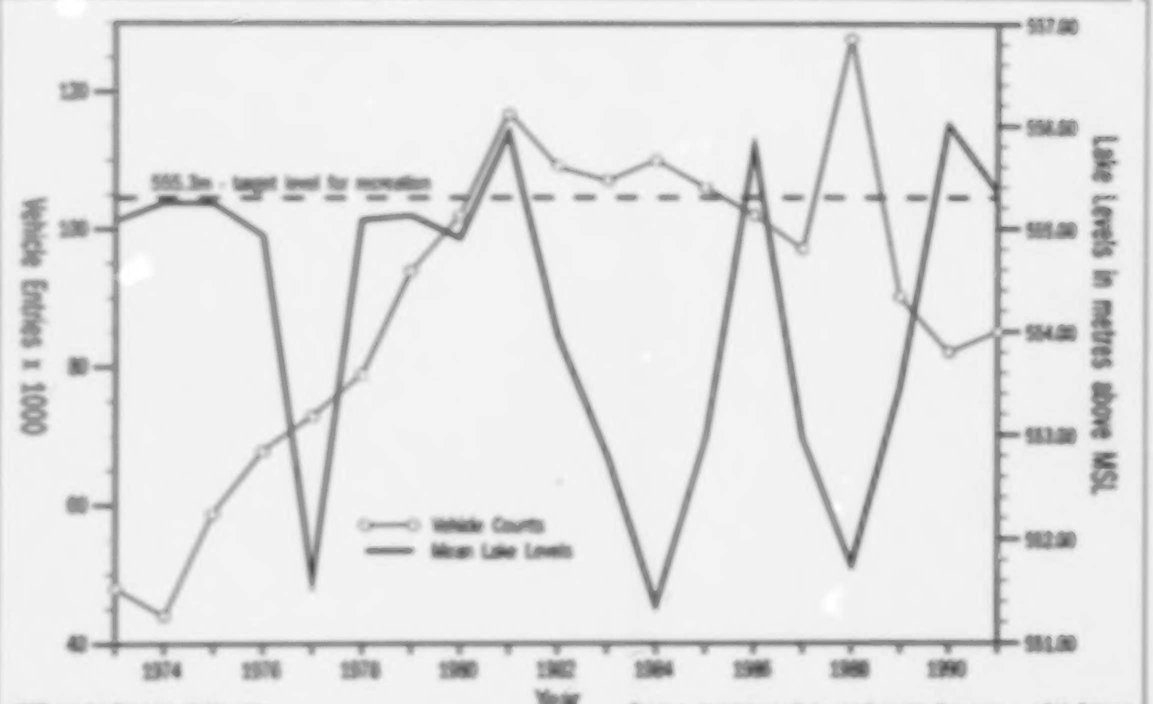
Sources: Canada - Saskatchewan, South Saskatchewan River Basin Study, Technical Appendix II C, Water Use.
PPWB - Water Demand Study, Historical and Current Water Uses in the Saskatchewan - Nelson Basin, Appendix 5, Recreational Water Uses.
Saskatchewan Property Management Corporation, Central Survey and Mapping Agency.

FIGURE 22.1. Water-based recreation sites in southwest Saskatchewan



Source: Environment Canada, Water Resources Branch

FIGURE 22.2. Lake Diefenbaker levels during summer recreation season: Victoria Day to Labour Day, 1984



1973 was the first year vehicles were counted at all three provincial parks

Sources: Saskatchewan Parks and Renewable Resources (Park Entries)
Environment Canada, Water Resources Branch (Lake Levels)

FIGURE 22.3. Mean summer water levels for Lake Diefenbaker and vehicle entries at the lake's provincial parks

grew throughout the 1970s, a growth phase in the parks system, and also a period of favourable lake levels, to peak in 1981. Low lake levels in 1977 did not appear to impair the upward trend in visitation.

The 1980s were a particularly dry decade, with only 1981 and 1986 meeting a recreation optimum. The long term secular decline in visitation during the 1980s continued unabated, except for 1988, when visitation peaked, to return to the decline path the following year. In 1986, when lake levels rebounded, visitation did not respond, or even the next year to allow a one-year lag in response.

The rate of economic growth also slowed in the province during the 1980s, which could help to explain the visitation trend. Economic indicators generally grew at a healthier pace throughout the 1970s. Estimates prepared from Statistics Canada sources indicate that Gross Domestic Product per capita grew in the range of 6 percent in the 1970s, in comparison to 4 percent during the 1980s. Unemployment rates averaged from 2.5 to 5 percent during the 1970s, in contrast to 4 to 8.5 percent during the 1980s (Statistics Canada, 1991a; 1991b; 1991c).

The proportion of people in younger age groups is widely considered in the recreation literature as a measure of potential demand for outdoor recreation. The proportion of population less than 25 years of age in the Province of Saskatchewan dropped significantly throughout the period, even though population levels grew by a modest 7 percent from 1971 to 1990. In 1971, 48 percent of the population were in this age group. By 1991, the proportion had shrunk to 38 percent.

The year 1988 is a particular anomaly, as a year of severe drought, yet the highest visitation to date was recorded. Vehicle counts provided by Saskatchewan Parks and Renewable Resources indicate that almost all the Provincial Parks easily accessible from the major population centres of Saskatoon, Regina-Moose Jaw and Swift Current (Figure 22.1) sustained increases in visitation, averaging 26 percent. Lake Diefenbaker Provincial Parks increased visitation by 32 percent (Figure 22.3). This was despite poor water quality conditions generally at parks away from Lake Diefenbaker, and extreme low water conditions at Lake Diefenbaker. A hot dry summer could partly explain increased visitation. As well economic concerns with respect to anticipated extraordinary impacts on drought on farm and related sector incomes, may have encouraged recreational users to stay close to home and within the province for summer holidays.

ECONOMIC MODELS OF RECREATION: POTENTIAL GUIDE TO WATER MANAGEMENT

The relationship between a recreation site, its attributes, and the wishes, desires, and socio-economic circumstances of the population using the site is a complex one. Water levels and quality play a major role in the value and use of a site, especially at Lake Diefenbaker. The focus of water management is to affect these attributes, to result in an improvement in social well-being for those enjoying the site.

In order to isolate the impact that management can play, the other factors that influence recreation behaviour need to be considered. In particular, a general model incorporating site characteristics (supply side), and user characteristics (demand side) is required. The difficulty is that the recreation experience (*i.e.*, the product/service involved) is not normally traded in markets.

In the economics literature, two alternate evaluation approaches have been developed in order to overcome the problem that the recreation experience is outside the market system. The first approach is referred to as the direct or contingent value method (CVM), and the second as the indirect or travel cost method.

The first method imposes a hypothetical market within which participants (people asked in a questionnaire interview) are asked their willingness-to-pay to improve or forego a hypothesized decline in quality of their recreational experience. A whole host of issues have been raised that the hypothetical situation leads to numerous biases, including the credibility of the questions, which leads to responses that are not related to rational economic behaviour (Freeman, 1979).

The second (indirect) approach utilizes the fact that recreational users may spend considerable time and resources to travel and enjoy water-based recreation. This revealed market behaviour is assumed to demonstrate the willingness-to-pay to enjoy the services of a given site. However, the approach does not effectively deal with changes in the quality of that experience if attributes of the site change. Cross-section studies, utilizing the results of travel cost models for a variety of sites on a regional basis where travel costs and site attributes vary, have been used to capture the economic effect of changes or differences in site attributes. The results of these investigations have been disappointing (Smith *et al.*, 1986).

For both methods, the economic value of a recreation experience or change with respect to the quality of that experience is the willingness-to-pay associated with it. The direct method asks participants what they are willing-to-pay to secure the experience or change with respect to the quality of that experience. The indirect method compares the difference in travel costs, as a measure of price and the marginal value of the experience, as a measure of the quality difference.

What is proposed in this study is a combination model incorporating the advantages of the travel cost and willingness-to-pay approaches. A hybrid travel cost is modified to incorporate a willingness-to-pay parameter (based on interview data) to capture the value of an improvement in the recreation experience.

The combination model proposed is as follows:

$TDYSYR = f\,(TC, SE, Q_b, Q_{bi}, TC_a, Q_{ba})$

$Q_{bi} = f\,(SE, TC, TC_a, TDYSYR, B)$

TDYSYR = participation in recreation in days this year

TC = travel cost, a proxy for the price of recreation

TC_a = travel cost to alternate sites

SE = socio-economic factors related to recreation participation (age, income, type of activity, etc)

Q_b = quality of the recreation experience, in terms of facilities, water quality

Q_{SA} = quality of alternate sites

Q_{R1} = willingness-to-pay to improve the quality of the recreation experience with respect to lake level

B = effects of bias in asking questions about willingness-to-pay

A travel cost model is used to estimate the first equation, which evaluates the consumers' surplus or economic value of the existing and improved recreation experience. The second equation estimates the factors associated with the willingness-to-pay to achieve better lake levels. The data base for both equations of the model is a survey of recreational users conducted by Environment Canada at Danielson Provincial Park at Lake Diefenbaker during the extreme low water event experienced during the summer of 1984 (Bjonback, 1986).

Figure 22.4 provides a basis to describe, in theoretical terms, how the model is expected to evaluate the economic consequences of extreme low water levels. The model in Figure 22.4 is a variant, modified for the lake levels issue, of one developed by Freeman (1979), and Smith *et al.* (1983) used to describe the economic value to recreation activities of water quality improvements.

Each of the schedules in Figure 22.4 represents a situation with (Q_1) and without (Q_0) the lake level improvement. Q_0 is the situation without a lake level improvement, and Q_1 reflects the respondents' willingness-to-pay (in response to a direct question) to realize an increase in water level to the normal (optimum) level for recreation use.

TC_0 is the average travel cost (or proxy average price) of the typical recreational users to participate in activities at Lake Diefenbaker. $TDYSYR_0$ is the current level of participation in recreation. Those who do not wish to pay a premium to realize an increase in water levels at the current rate of activity of $TDYSYR_0$ (days per year) of recreation at Lake Diefenbaker are at B, and those who are willing-to-pay to improve water levels would be willing to pay a premium above B at E. Those who are willing-to-pay as well would like to increase their participation to A, given an improvement in water level conditions.

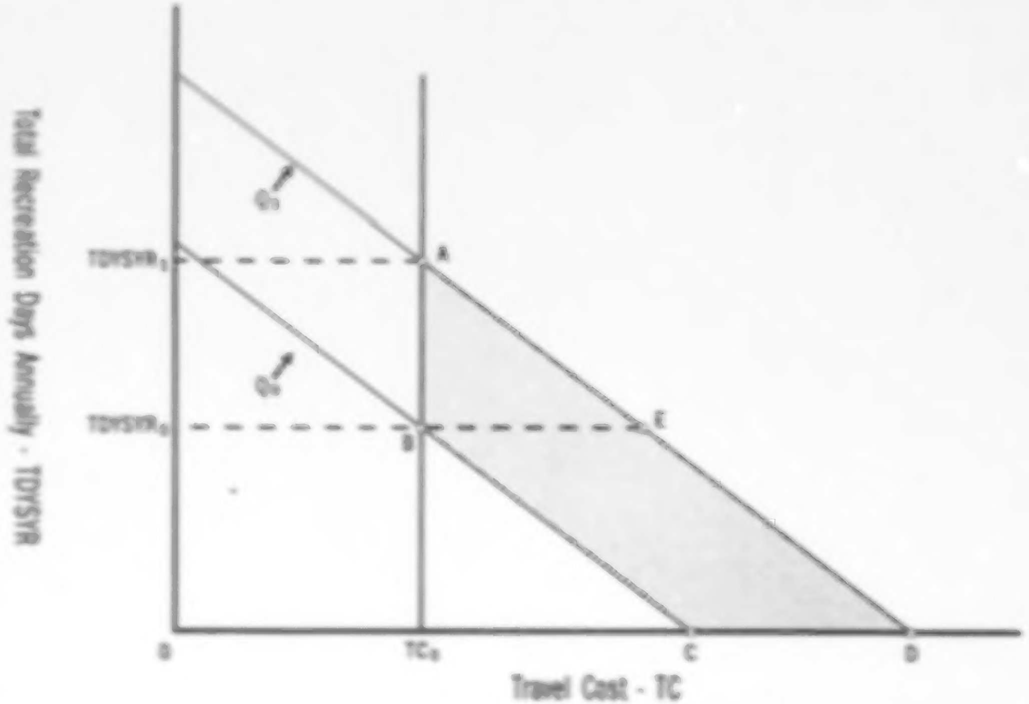


FIGURE 22.4. Model of recreation behaviour

Those individuals who are not willing-to-pay for an improvement in water levels pay area O-$TDYSYR_0$-B-TC_0 per year to realize O-$TDYSYR_0$ days of recreation. In actual fact, they would have been willing-to-pay much more for the first few days of recreation, above O-TC_0, up to O-C. The triangle TC_0CB reflects the additional amount that these recreational users would have been willing-to-pay to realize $TDYSYR_0$ days of recreation. This area is defined as consumers' surplus (CS) associated with the recreation experience over and above the cost of (O-TC_0-B $TDYSYR_0$) required to realize $TDYSYR_0$ days of recreation. This is defined as the economic value of O to $TDYSYR_0$ visits of recreation over and above the costs of experiencing it.

A similar argument can be made to define the consumers' surplus of those recreational users willing-to-pay a premium to increase water levels at $TDYSYR_0$ days of recreation. These recreational users would be willing-to-pay an additional area BEDC in terms of consumers' surplus at the current level of activity ($TDYSYR_0$), and over and above those not willing-to-pay, to secure the water levels improvement. In addition, if there were an improved water level, those willing-to-pay for the improvement would expand their participation to A. In consumers' surplus terms, the economic value of this expansion would be area ABE. Therefore, the aggregate economic value of the water levels improvement would be area ABCD.

Empirical Results

The estimated equations for the travel cost-contingent value models are presented in Table 22.1. Definitions of each variable used in the models are provided in Table 22.2. Four alternate specifications and estimation procedures were performed: linear model, estimated by ordinary least squares (OLS); linear model, estimated by two stage least squares (2stLS); log-linear model (2stLS), and log model (2stLS).

The first equations for each model (TDYSYR) were estimated using the individual observations approach (Gum and Martin, 1975), whereby observations for individual park visitors are used to estimate visitation. All data were directly utilized from Bjonback (1986), except for the Travel Cost (TC) variable. Reported total trip costs from this study were modified to

TABLE 22.1
Estimated Travel Cost-Contingent Value Models, Lake Diefenbaker Water-Based Recreation Activities

(1) Linear Model (2sLS)

TDYSYR = 26.316 + 1.020 AMTDY - 0.033 TC + 12.716 ACTIVIA
(7.136)* (2.936)* (-2.119)* (2.416)*

R^2 = .0807
F = 7.112
n = 209

AMTDY = 2.291 ACTIVIL + .035 TDYSYR + 16.612 SEAS
(1.535)** (1.767)** (10.640)*

R^2 = .4203
F = 79.263
n = 209

(2) Linear Model (OLS)

TDYSYR = 42.124 - 16.570 ACTIVIL + 0.909 AMTDY - 0.047 TC
(11.692)* (-2.406)* (4.423)* (-3.146)*

- 16.562 CITYS - 15.629 ACTIVIK
(-3.295)* (-2.356)*

R^2 = .1916
F = 18.237
n = 209

AMTDY = -3.590 - 1.493 ACTIVIA + 16.664 SEAS + 0.584 INDPTB
(-2.676)* (-1.426)** (12.212)* (2.955)*

+0.026 INDPTH + 0.037 DELPTA + 5.256 INTVWRB1
(1.296)*** (3.026)* (4.346)*

R^2 = .4734
F = 32.311
n = 209

continued

TABLE 22.1
Estimated Travel Cost-Contingent Value Models, Lake Diefenbaker Water-Based Recreation Activities (cont'd)

(3) Log Linear Model (2sLS)

LTDVSYR = 3.686 + 0.349 VISTYPC - 0.0027 TC - 0.0009 DUPTA
(39.477)* (2.572)* (-6.198)* (-2.207)*

-0.0179 DELPTO + 0.136 LAMTDV
(-2.540)* (2.842)*

R^2 = .2206
F = 12.030
n = 259

LAMTDV = -0.382 CITY1 + 0.960 OCCUPATN6 + 3.486 SEAS
(-1.953)** (1.890)** (13.600)*

+ 0.011 DUPTA - 0.312 LTDVSYR - 0.013 DUPTN + 0.009 DELPTA
(1.936)** (-5.380)* (-2.430)* (1.861)**

R^2 = .7136
F = 28.412
n = 259

(4) Log - Log Model (2sLS)

LTDVSYR = 3.516 + 0.548 VISTYPA + 0.411 VISTYPC + 0.422 ACTIVS1
(15.064)* (2.402)* (2.490)* (2.208)*

+0.091 LAMTDV - 0.372 LTC + 0.098 LDUPTB + 0.330 LDUPTD
(1.769)** (-6.210)* (2.400)* (1.582)**

R^2 = .3626
F = 8.959
n = 168

LAMTDV = -0.980 + 0.548 ACTIVS1 + 1.041 OCCUPATN6 + 3.868 SEAS
(-1.715)** (1.237)*** (2.576)* (11.145)*

+0.346 LBAGE - 0.207 LVACDYS + 0.212 LDELPTA
(2.840)* (-1.453)*** (4.087)*

+0.347 LDELPTC + 0.411 LDELPTD
(1.489)*** (1.912)**

R^2 = .4866
F = 20.964
n = 168

* significant at 5 percent
** significant at 10 percent
*** significant at 20 percent
n number of observations

TABLE 22.2
Variables Used in Estimated Travel Cost-Contingent Value Models

Variables

TDYSYR = Total Days Recreation this year at Lake Diefenbaker
LTDYSYR = Natural log of TDYSYR
AMTDY = Amount per day that respondent is willing-to-pay to improve water level to desirable level for recreation
LAMTDY = Natural log of AMTDY
ACTIVIA = Swimming is primary activity
ACTIVIG = Pleasure boating is primary activity
ACTIVK = Fishing from shore is primary activity
ACTIVL = Fishing from boat is primary activity
TC = Travel and tie cost to visit site this trip
LTC = Natural log of TC
SEAS = Those respondents choosing to pay on a seasonal basis (yearly) to improve water level to desirable level for recreation
CITYS = Residents of Saskatoon
INJPTA = Number of points (0 to 100) chosen by respondent to indicate strength of positive site features - water level
INJPTB = Number of points (0 to 100) chosen by respondent to indicate strength of positive site features - water clarity
INJPTD = Number of points (0 to 100) chosen by respondent to indicate strength of positive site features - water odour of water
INJPTH = Number of points (0 to 100) chosen by respondent to indicate strength of positive site features - facilities
INJPTN = Number of points (0 to 100) chosen by respondent to indicate strength of positive site feature - species of fish available
DEJPTA = Number of points (0 to 100) chosen by the respondent to indicate strength of negative site feature - water level
DEJPTC = Number of points (0 to 100) chosen by respondent to indicate strength of negative site feature-water temperature
DEJPTO = Number of points (0 to 100) chosen by the respondent to indicate strength of negative site feature - chance of catching a fish
OCUPATM = Occupation in manufacturing
LMAGE = Log of age of eldest person in party
LVACDYS = Log of vacation days

L prior to INJPT, DEJPT variables indicates natural log include the time cost of travel, valued at the minimum wage for the Province of Saskatchewan in 1984 ($9.84 per hour).

The estimated coefficients for the variables in each equation are all significant at either the 5 percent, 10 percent or 20 percent level. The t-value of each estimated coefficient appears in brackets. Although R^2 values are low for some of the travel cost equations, F-values for each equation indicate that the independent variables as a group are significant (at 5 percent) in explaining the variation in the dependent variable.

For simultaneous equation systems, such as those in Table 22.1, two-stage least squares, or other estimation procedures such as three stage least squares and maximum likelihood methods are generally preferred. These procedures take into account information contained in other equations of the system in the estimation of the equation under consideration. Ordinary least squares methods take into account only information in the equation being estimated, and consequently the estimated coefficients are biased and inconsistent. This is a consequence of the incorporation of endogenous variables to the system as explanatory variables in equations being estimated (such as AMTDY in the first equation of each model), which leads to a potential association between the endogenous variable and the stochastic error of the equation. Two-stage least squares approaches which are widely used to estimate simultaneous equation systems, produce consistent estimators, but still have a problem of bias.

Both two-stage and ordinary least squares (OLS) are utilized in this study, as OLS methods even with these problems, is an efficient technique, and tends to be insensitive to model specification error. As well, little is known about the sample properties of any estimation technique to judge OLS better or worse than other techniques (Intriligator, 1978). The property of OLS, its insensitivity to model specification error, is of particular value to this study. The exact specification of which variables should be included in each equation, in a field such as recreation where not a great deal is known about economic behaviour, is subject to significant uncertainty.

Measures of site quality and travel costs of substitute sites were not available and not used in the models (Q_{SA} and TC_{SI}, is described in previous "Economic Models..." section, above). This may cause an upward bias in the estimates value of the recreation site, as alternatives are not considered. Rosenthal (1987) has demonstrated in the estimation travel cost models for 11 reservoirs in the mid-western United States that omitting travel cost variables for substitute sites can increase resulting estimates of consumer surplus by an average of 60 percent.

Table 22.3 provides a summary of the influence of the range of explanatory variables, model-to-model, on the amount of recreation activity in days per year (TDYSYR) at Lake Diefenbaker. The elasticities presented in Table 22.3 indicate the percentage change in each of the explanatory variables, and as a ratio of the induced percentage change in recreation activity.

TABLE 22.3
Elasticities Indicating Percent Changes of Explanatory Variables With Respect to Percent Induced Changes in TDYSYR (Number of Recreation Days This Year)

Model	LAMTDY	TC	ACTIVL	ACTIVA	ACTIVO	ACTIVX	CITYS	VISTYPA	VISTYPC
(1)	+.15	-.05	-	+.12	-	-	-	-	-
(2)	+.14	-.07	-.07	-	-	-.09	-.16	-	-
(3)	+.14	-.56	-	-	-	-	-	-	+.49
(4)	+.09	-.37	-	-	+.62	-	-	+.47	+.47

Model	INJPTA	DEJPTO	LNJPTB	LNJPTD
(1)	-	-	-	-
(2)	-	-	-	-
(3)	-.50	-.40	-	-
(4)	-	-	+.09	+.24

Both the preference to pay for an improvement in water level, AMTDY (positive) and travel costs, TC (negative), have a consistent influence in each model, in line with theoretical expectation outlined in Figure 22.4. The price elasticity of demand for recreation activity (travel cost, TC, here a the proxy for price), ranges from -0.05 to -0.56. Those respondents who indicated a preference and willingness-to-pay for an improvement in water level to the minimum desirable level for recreation (AMTDY) also demonstrated a consistently higher level of recreation activity. The elasticity estimates varied in a narrow range between +.09 to +.15, which means for each unit increase, say 10 percent in AMTDY, recreation days increased approximately 1 to 1.5 percent.

A variety of other independent variables, related to participant type and preferences for site features, affected behaviour of recreation activity. There appeared to be no specific consistent pattern of such variables that appeared in more than one model.

In terms of recreation activity, swimming (ACTIVIA), and especially boating (ACTIVIG) as primary activities appeared to have some influence in increasing recreation activity in models (1) and (4) respectively. Fishing from a boat (ACTIVIL) and shore (ACTIVIF) were associated with a reduced level of recreational activity. Visitor type, VISTYPA - permanent resident of the area, and VISTYPC - staying at local accommodation (as opposed to day visitors, the other major group), had a particularly strong positive influence on recreation participation (days per year) in models (3) and (4).

Preferences for site features also played a major role in explaining recreation behaviour in models (3) and (4); but did not appear in models (1) and (2). Those participants who were not affected by low water levels, and actually enjoyed them (INJPTA) had a marked tendency for reduced recreation participation (eqn. [3]). Another important negative site characteristic is the chance of catching a fish (DEJPTO) in model (3). This could be related to a perception that fishing success at Lake Diefenbaker is lower than competing sites.

Positive site features of Lake Diefenbaker affecting the amount of recreation activity include water clarity (LINJPTB) and (lack of) odour (LINJPTD). In model (4), LINJPTB is the most important (quantitatively) variable explaining the amount of recreation activity. Those recreational users who more highly value the water clarity at Lake Diefenbaker tend to have a higher annual rate of recreation activity.[1] The lack of odour in the water is particularly important (LINJPTD) as well in boosting recreation activity in model (4). This likely reflects, along with water clarity, the relative attractiveness of Lake Diefenbaker in relation to competing sites which have much lower water quality.

Of particular interest is the role of the CITYS variable in model (2). Although residents of Saskatoon (CITYS) are about one-third of the total visitors to Lake Diefenbaker, they are likely to spend on average 16 days per year less recreating at the lake than what would be expected, given distance, travel costs, and other variables explaining visitation, would indicate. The availability of the South Saskatchewan River for recreation, both within the city and immediately upstream, which is on the way to Lake Diefenbaker, could be considered as providing a comparable, high quality experience at lower travel and time cost. Residents of areas to the south and at similar distance from Lake Diefenbaker do not have this opportunity.

Table 22.4 provides a summary of the influence of the range of explanatory variables, model-to-model on the amount users are willing-to-pay per day for an improvement in water levels (AMTDY). The interpretation of figures is similar to that in Table 22.3.

The SEAS variable is the only variable that appears in all models, and it has the largest aggregate effect on AMTDY. This is not surprising given its function to reflect the preference of those respondents to pay a fee on a seasonal basis, similar to the Park annual fee structure, rather than on a daily basis.[2] The premium respondents would pay on a seasonal basis was concentrated in the narrow $19.00 to $20.00 range for models (1), (2), and (4). The premium for model (3) is estimated at $30.28.

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[1] Although the elasticity is only 0.09, the *absolute* influence of LINJPTD is very high in terms of explaining visitation.

[2] Although the elasticity is only 0.09, the *absolute* influence of LINJPTD is very high in terms of explaining visitation.

TABLE 22.4
Elasticities Indicating Percent Changes of Explanatory Variables with Respect to Percent Induced Changes in AMTDY (Amount Per Day Respondent Willing-To-Pay for Lake Level Improvement)

Model	L.TDYSYR	SEAS	ACTIVA	ACTIVL	INJPTA	INJPTB	INJPTH	INJPTN
(1)	+.23	+.62	-	+.08	-	-	-	-
(2)	-	+.81	-.12	-	-	+2.15	+.07	-
(3)	-.01	+2.10	-	-	+1.97	-	-	-1.87
(4)	-	+3.03	-	+.57	-	-	-	-

Model CITYS	LDEJPTA INTVWRS	LDEJPTC	[illegible]	LDEJPTO	OCUPATN	[illegible]	[illegible]	LMALELHACDYS
(1)	-	-	-	-	-	-	-	-
(2)	+.33	-	-	-	-	-	-	+.40
(3)	+2.10	-	-	-	-	-	-1.30	-
(4)	+.21	+.25	+.01	+1.54	+.34	-.60	-	-

The second most important variable in explaining the behaviour of AMTDY are the site preference variables, which appear in every model except (1). Not surprisingly, the intensity of negative feelings toward low lake levels as it would affect enjoyment of the recreational experience (LDEJPTA, or DEJPTA) increased the propensity to pay a fee to increase water levels. Other negative site features that had a positive, but smaller aggregate impact on AMTDY, and only appear in one model (4), include water temperature DEJPTC, and chance of catching a fish DEJPTO. Thus, it appears that those who are dissatisfied with Lake Diefenbaker on these two (non-lake level) accounts, are still interested in paying a relatively larger amount for lake level improvements.

Positive features that have a positive influence on AMTDY in various models include lake level INJPTA, water clarity INJPTB, and facilities INJPTH. Of these only water clarity, an outstanding feature of Lake Diefenbaker, has a particularly strong impact on AMTDY in model (3). The facilities at Lake Diefenbaker appear to have a mild (positive) impact in model (2). The water level coefficient in model (3), although small, is statistically significant and somewhat surprising. It would appear inconsistent for respondents who preferred the relatively low lake levels, that they would be willing-to-pay more than average to increase lake levels. This could be attributed to interviewer error in explaining the nature of the preference questions. Again in model (3), those respondents indicating that the species of fish available increased their enjoyment (INJPTN) were less willing-to-pay for a lake level improvement. This would appear to contradict the results from DEJPTO for model (4) above.

Variables reflecting the socio-economic background of respondents play an important role in only model (4). The age of the eldest member of the party LMAGE and occupation in manufacturing OCUPATM are associated with a higher value for an increased lake level, and an increasing number of vacation days VACDYS are associated with lower values. A variable for geographic origin appears only in model (3). Residents of Saskatoon CITYS in this model are willing-to-pay about 30 percent less, all other factors constant, for an improvement in lake level.

The role of visitation (TDYSYR) on willingness-to-pay to improve lake levels is ambiguous among the alternate models. It is positive in model (1), and negative in model (3). It is likely that the relationship is more complex than that posited, for example quadratic, where the first few days would have a positive impact on willingness-to-pay, such that guaranteed number of days of higher lake levels is desired when vacations are short. And for longer vacation periods, when alternatives can be pursued, a negative influence on willingness-to-pay could eventually be experienced.

The influence of interviewer bias (INTVWRBG) is noted in model (2), but did not appear in any other model. Testing for interviewer bias is common practice in willingness-to-pay surveys. The effect is substantial, for model (2), a 40 percent increase in the mean value of AMTDY. A correction factor was applied to the subsequent estimates of consumers' surplus for the lake level improvement, though the effect of AMTDY within the TDYSYR equation.

In summary, visitor and activity type appeared to play a stronger role, and appeared more frequently in explaining visitation TDYSYR. For AMTDY equations, visitor type did not appear, and activity type was relatively unimportant. The preferences for site features frequently appeared in both equations of each model, but the stability of behaviour of site features to explain the dependent variable appeared to be superior for TDYSYR equations rather than for AMTDY equations. Surprisingly, socio-economic factors appear to play a non-existent role in almost every case, except for the AMTDY equation of model (4). The absence of an income variable as well, which was included in the estimation process, but was dropped from consideration due to low t-values (low independent explanatory power), should be noted.

ASSESSMENT OF ESTIMATES OF CONSUMERS' SURPLUS

For each of the models in Table 22.1, estimates of consumers' surplus for Danielson Provincial Park at Lake Diefenbaker can be prepared, along the lines of the theory presented for Figure 22.4. The consumers' surplus (CS) values in Table 22.5 correspond to area $BCTC_p$. The WTP values in Table 22.5 refer to the willingness-to-pay, in consumers' surplus terms, of respondents to realize an increase in lake level, the shaded area of Figure 22.4, area ABCD. The estimation procedure followed that of Bowes and Schneider (1979). The estimates of consumers' surplus are also compared to other travel cost model studies for Danielson Provincial Park, which are outlined in greater detail below.

It was considered reasonable that Danielson Provincial Park (and other parks in the area in Saskatchewan) would not be a primary destination for parties travelling more than 500 kilometres. For parties travelling this far, Danielson Provincial Park would likely be one of 'multiple destinations' and not the primary purpose of the trip. Thus, the CS and WTP values for the present study have been estimated, truncating the TDYSYR functions at a travel cost (TC) of $150, which is three times the average Travel Cost per party of $51.42. Only 16 of the 209 observations for models (1) and (2), and eight of the 169 observations for models (3) and (4) are omitted by this procedure.

A similar truncation approach was applied in a zonal travel cost study of water-based recreational sites in the South Saskatchewan Basin in Saskatchewan for 1988 by UMA Engineering 1990. The results for Danielson Provincial Park are presented in Table 22.5, along with the results of a study completed for 1986 for nine sites in southern Saskatchewan, one

TABLE 22.5
Travel Cost Models, Comparisons of Estimates of Consumers' Surplus and Willingness-to-pay to Improve Lake Levels, Danielson Provincial Park

	In Dollars per Recreation Day CS	 WTP
Present Study - 1984		
Model 1 linear 2SLS	24.08	4.62
Model 2 linear OLS	23.66	2.91
Model 3 log linear 2SLS	16.08	.06
Model 4 log log 2SLS	18.04	.11
Kulshreshtha (1991) - 1986, log-linear OLS	7.42	n/a
UMA Engineering (1990) - 1988, log linear OLS	10.52	n/a

n/a = not applicable

of which was Danielson Provincial Park (Kulshreshtha, 1991). These two studies can provide a reference benchmark for the consumers' surplus estimates in the present study.

The linear models in the present study (models (1) and (2)) have consumers' surplus estimates about 40 percent higher than the log linear or log-log specifications. Willingness-to-pay for lake level improvements are also much higher for the linear models, some 40 times the estimates for the log variants. Also consumers' surplus for an improvement (WTP) as a percent of existing consumers' surplus also varies substantially, from 14 percent and 12 percent for models (1) and (2), to less than 1 percent for models (3) and (4).

The significant gap between the log models of the present study and the UMA estimates (some 60 percent), and the 2.3 fold difference between the linear models and the UMA estimates could be explained by differences in modelling technique. The UMA study utilized a zone-based travel cost model, and estimated travel costs as a function of vehicle operating costs to visit the site. The present study used reported travel costs of respondents plus the estimated costs of time to visit the site. The Kulshreshtha study used similar methods as the present study, yet the differences in results are even greater.

Such radical differences in consumers' surplus estimates in applying the travel cost model for the same population of recreational users have been reported in the literature. Smith (1988) found a 4.4 fold difference in consumers' surplus per trip to visit North Park Lake, Pennsylvania, utilizing a range of estimation methods, such as ordinary least squares and tobit, and alternate model specifications (log, linear).

CONCLUSIONS AND RECOMMENDATIONS

In order to effectively and consistently evaluate the economic effects of water level changes at Lake Diefenbaker, it would appear that a regional model that captures site substitution possibilities by recreational users is essential. Multiple site studies for the south central region of Saskatchewan are required to account for the relative attractiveness of sites. The role and economic value of water levels and quality conditions which vary over time, and which could be modified by water management practices could then be evaluated. Standards of model specification could then be defined for socio-economic models of recreation, that could lead to sufficiently stable results for policy and analysis in water management.

As Parkes (1973) noted, visitation dropped off by as much as 30 percent during periods of poor water quality in 1970 in the Qu'Appelle River system, the closest recreational area to Regina. The city is an important source region of recreational users to Lake Diefenbaker as well. Did these people end up at Lake Diefenbaker? Similarly, as reported by Beak and Associates Consulting Ltd. (1987), media coverage of low water levels discouraged visitors from visiting Lake Diefenbaker. Did they stay closer to home, in the Regina case, or at the Qu'Appelle Lakes?

As outlined in the *Final Report* of the Canada-Saskatchewan South Saskatchewan River Basin Study (1991b), increased economic development upstream in Alberta and in Saskatchewan are expected by 2020 to increase the frequency of extremely low water levels at Lake Diefenbaker. In order to provide assistance to decision making in the future, solid methodologies to evaluate the economic value of water of the many uses that share the waters of Lake Diefenbaker and downstream need to be developed. Models to evaluate the economic implications of low water levels for recreation use at Lake Diefenbaker in a regional context, considering inter-relationships with sites outside the basin, would be a critical component of the set of analytical tools required for this purpose.

ACKNOWLEDGEMENTS

Discussions on approach with Professor R. Walsh, Department of Agricultural and Natural Resource Economics, Colorado State University, and the research assistance of E. Smith, R. Herrington, G. Weiss, J. Rogers, G. Sahla, and M. Gilchrist of Environment Canada are gratefully acknowledged.

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